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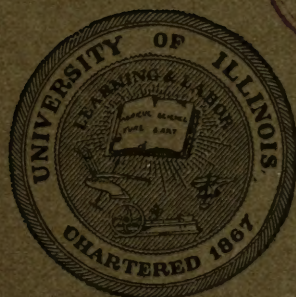
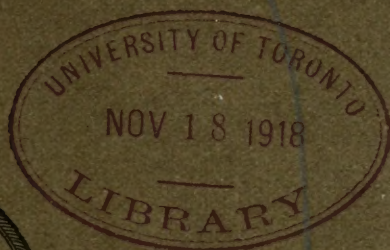
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THE ECONOMICAL USE OF
COAL IN RAILWAY LOCOMOTIVES



CIRCULAR No. 8

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UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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SEPTEMBER, 1918

THE ECONOMICAL USE OF
COAL IN RAILWAY LOCOMOTIVES

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ENGINEERING EXPERIMENT STATION

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THE ECONOMICAL USE OF COAL IN RAILWAY LOCOMOTIVES

I. INTRODUCTION

1. *Scope and Purpose.*—Conditions brought about by the war place upon all classes of persons responsibilities which are inescapable. The positive need for the coöperation of the individual and for the exercise of every personal effort in the prosecution of the war is daily becoming more apparent. It is recognized that the greatest service which the individual not actually engaged in military service may render lies in doing what he may to conserve the nation's supplies. One of the greatest opportunities open for service in this respect is in connection with the nation's fuel supply. The successful issue of the war depends upon the economical use of coal both in the home and in the industrial plant and locomotive.

The Engineering Experiment Station of the University of Illinois has undertaken to prepare for users of fuel certain publications containing suggestions and advice relating to fuel conservation. Circulars dealing with the use of coal in heating homes and in generating power have been published as have also bulletins and circulars relating to the extraction of coal in the mines and its storage. The present circular has the purpose of helping railway officials and employes in their efforts to save coal. While it contains little that is new, it presents a simple statement of the facts concerning the choice, distribution, storage, and use of coal, and offers some conservative suggestions concerning the ways in which coal may be burned economically.

This circular is issued with a full understanding and appreciation of the intelligent and wide-spread effort which railway men are making to save coal, and it aims only to supplement these efforts as it may. If it succeeds in stimulating greater interest in the subject and in bringing even a few helpful suggestions to those into whose hands it may fall, it will have served its purpose.

2. *Authorship.*—The facts presented in this circular have been compiled by a committee consisting of J. M. SNODGRASS, Assistant Pro-

fessor of Railway Mechanical Engineering (Chairman), MAJOR E. C. SCHMIDT, U. S. R. Engineer, Conservation Division U. S. Fuel Administration, and Professor of Railway Engineering, University of Illinois (on leave of absence), H. H. STOEK, Professor of Mining Engineering, S. W. PARR, Professor of Applied Chemistry, and C. S. SALE, Assistant Professor of Civil Engineering and Assistant to the Director of the Engineering Experiment Station.

This committee has had the assistance of an advisory committee consisting of E. W. PRATT, Assistant Superintendent of Motive Power, Chicago and Northwestern Railway Company, Chicago, Ill., W. L. ROBINSON, Fuel Supervisor, Baltimore and Ohio Railroad Company, Baltimore, Md., A. N. WILLSIE, Chairman, Fuel Committee, Chicago, Burlington and Quincy Railroad Company, Chicago, Ill., TIMOTHY SHEA, Acting President, Brotherhood of Locomotive Firemen and Enginemen, Cleveland, O., A. B. GARRETSON, President, Order of Railway Conductors of America, Cedar Rapids, Ia., W. S. STONE, Grand Chief, Brotherhood of Locomotive Engineers, Cleveland, O., O. P. HOOD, Chief Mechanical Engineer, Bureau of Mines, Washington, D. C., D. M. MYERS, Advisory Engineer on Fuel Conservation, U. S. Fuel Administration, Washington, D. C., and C. R. RICHARDS, Dean of the College of Engineering and Director of the Engineering Experiment Station, University of Illinois. Each member of this advisory committee has personally reviewed the original manuscript and a meeting was held at Urbana on March 22, 1918, at which the manuscript was examined in detail. The authors gratefully acknowledge the valuable assistance and coöperation of the members of this committee and feel that the value of the publication has been greatly increased as a result of their efforts.

II. THE AMOUNT OF COAL USED BY RAILWAYS

3. *Fuel Burned in Railway Locomotives.*—A considerable portion of the coal bought by railways is used in stationary power plants at shops and roundhouses, and in heating plants at stations and elsewhere. While there are many opportunities for effecting greater economy in the use of stationary plant fuel, this subject is not considered in the present circular; it has already been covered in previous publications* issued by the Station. The use of oil fuel, also, is not discussed, since oil is used on only a few roads and since the extent of its use, under prevailing prices, is decreasing. Many of the suggestions concerning coal are, however, obviously applicable to oil.

During the calendar year of 1917 there were produced in the United States about 545,000,000 tons (2000 pounds) of bituminous or "soft" coal and about 92,000,000 tons of anthracite. The railways of the country used 26 or 27 per cent of the bituminous coal and 6 or 7 per cent of the anthracite, or a total of about 155,000,000 tons. About 140,000,000 tons or about 22 per cent of the total production were burned in locomotive fireboxes. The corresponding amount for the year 1918 is estimated to be about 150,000,000 tons. This fuel is referred to in this circular as locomotive coal. It is not easy to appreciate the significance of such a quantity. It would take 3,000,000 fifty-ton capacity cars to hold it; every coal car in the country would need to be loaded more than three times each year to carry the locomotive coal alone.

Trains carrying it in one load would have a total length of 24,000 miles, or a distance equivalent to the circumference of the earth. During the year 1918 locomotive coal will probably cost the railways more than \$500,000,000; thus the fuel cost will be the largest single item of operating expense except only the wages of trainmen and engineers.

Obviously the saving of even a small percentage of the large quantity of fuel consumed by locomotives is a result worth striving for. In

*Circular 4, entitled "The Economical Purchase and Use of Coal for Heating Homes with Special Reference to Conditions in Illinois," 1917, and Circular 7, entitled "Fuel Economy in the Operation of Hand Fired Power Plants," 1918, of the Engineering Experiment Station of the University of Illinois.

view of all the earnest effort already being expended to save coal, the possibility of effecting a still further saving is not at once apparent. A study of the problem, however, discloses many means of effecting greater economy which have not as yet been generally employed. The saving on each scoopful of a piece of coal as big as an ordinary egg would amount to one per cent or 1,500,000 tons. Even when firing a modern freight locomotive on a heavy grade, one less scoopful of coal every fifteen minutes, or one less scoopful every three or four miles, would effect a similar saving. A little more personal interest and more care will reduce coal consumption by such a percentage even on railroads where the practice is already excellent, and where fuel conservation is already receiving close attention. On many railroads where efforts at fuel economy are not so well organized much greater savings can undoubtedly be effected.

By a nation-wide attack on this problem involving the concerted interest and action of all concerned, practices relative to fuel conservation may be so improved as to save at least 9,000,000 tons of coal per year. This amount is more than enough to supply the needs for an entire year of such a system as the Chicago and Northwestern Railway, or the Atchison, Topeka and Santa Fe, each of which operates about two thousand locomotives. This amount of coal would be sufficient to coal a fleet of transports, United States to France, which would be capable of carrying an army of three to five millions of soldiers with supplies and equipment.

III. WHAT BECOMES OF THE COAL AND THE HEAT

4. *Sources of Loss.*—Any attempt to economize in the use of fuel must be based upon a clear understanding of what happens to the coal from the time it is loaded at the mines until it reaches the locomotive firebox, and what becomes of the heat liberated in the firebox. Each operation from the mining of the coal to its combustion in the firebox presents possibilities of loss or waste.

In the following sections the several possible sources of waste are discussed and the ways in which coal may be used without doing any useful work whatever are pointed out. It is not the purpose to consider at this point the ways in which savings may be effected, but simply to indicate the points to which attention and effort should be directed.

5. *Losses in Transportation and Storage.*—In transit from the mines to the chutes there is some direct loss of coal from the cars due to carelessness in loading. Probably this loss is not large, but it can be and should be entirely eliminated. At the chutes little coal, as such, is lost but its fuel value is sometimes considerably diminished by improper handling which causes undue breakage and which ultimately results in a direct loss on the locomotive by increasing the cinder discharge through the stack because of the excess of fine material in the coal.

At certain seasons and under certain market conditions it is essential for the railways to store large quantities of coal, generally in outdoor piles. These piles frequently take fire with the result that the fuel value of the coal so stored is destroyed or impaired. Except in rare instances, this is a preventable loss resulting from improper methods of storage. These losses can generally be avoided by exercising precautions which are discussed in a later chapter of this circular.

6. *Coal Consumed when the Locomotive is Standing.*—About one-fifth of all locomotive coal is consumed at periods when the locomotive is not doing useful work, in firing up, in waiting for trains, in standing on sidings and passing tracks, in delays at terminals, and in waiting at ashpits. During the year 1918 nearly 30,000,000 tons of coal will be used during these periods.

While this consumption is not directly productive, it is, of course, not all to be regarded as waste. Locomotives must be fired up and their fires must be cleaned; a certain amount of time must also inevitably be spent in yards, terminals, and sidings. All these are essential activities incident to operation, but since so large an amount of coal is involved it is clearly necessary that under present conditions these periods should be reduced to a minimum. The saving of fuel in this connection reduces itself to a question of saving time in these operations.

This is a part of the fuel conservation problem over which trainmen have little or no control; roundhouse men can help in one or two respects, but the chief responsibility lies with operating officials and dispatchers. The results to be obtained will come chiefly from forethought and attention to the details of operation. The best results have undoubtedly not been reached even on the best managed and best equipped roads. The magnitude of the amount of coal involved should provide a strong incentive to renewed effort and care.

It is proper to point out, however, that on some railroads any very radical decrease in this part of the coal consumption involves expensive and time-consuming physical improvements such as the redesign of terminals and the enlargement or increase in the number of sidings. Such work requires large expenditures of capital and cannot always be done hurriedly even when the money is available. The responsibility for determining whether such improvements may be made lies, of course, with executive officers. Where such improvements looking toward extensive savings are impossible, that fact should not diminish the enthusiasm for attempting to effect the smaller savings which are possible in any situation.

7. *The Distribution of the Heat Generated in the Firebox.*—There remain four-fifths of the locomotive coal which is burned while locomotives are hauling trains. For the year 1918 this will amount to about 120,000,000 tons. Naturally, the campaign for economy has always been most vigorously waged with respect to this fuel and the greatest effort in the future must continue to be directed at the possibility of effecting greater savings in the use of it.

In this section it is the purpose to show what becomes of the heat generated in burning this coal—to show, that is, where the heat goes while the locomotive is at work on the road, always with the view of

disclosing the avenues of loss and waste as well as the points at which efforts at conservation are likely to prove most effective.

Although many avenues of waste occur in connection with the actual burning of the coal and the heat generated in the firebox, it should be recognized that enginemen have no control over some of the losses which occur. Many kinds of fuel waste can be prevented only by better locomotive maintenance, and by better roundhouse and shop practice. Motive power officials and shop and roundhouse employes must assume the responsibility for heat losses which result from poor locomotive maintenance.

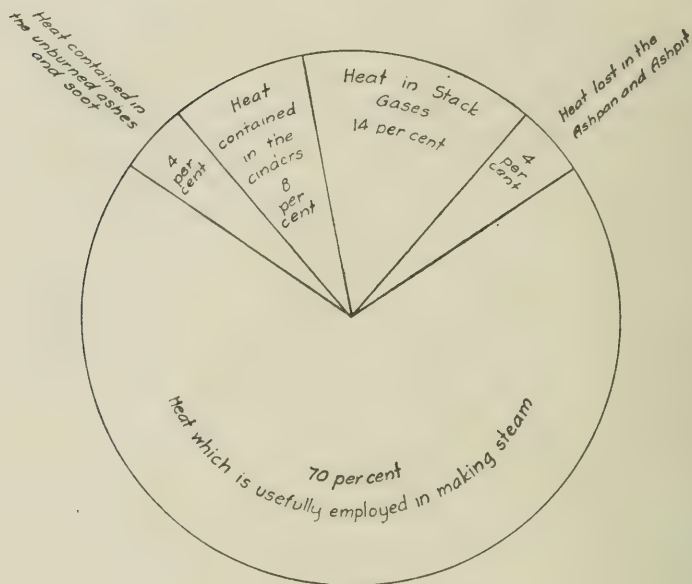
Certain maintenance improvements and certain matters of design such as the installation of washout apparatus, superheaters, or brick arches require such expenditures of capital and time that they cannot be considered matters for emergency treatment.

The Firebox and Boiler

Fig. 1 shows graphically what may become of the heat contained in the coal which is shoveled into the firebox in so far as the firebox and boiler are concerned. The proportions are intended to be representative of a modern locomotive, burning from 70 to 80 pounds of western bituminous coal per square foot of grate surface per hour.

The largest area represents that portion of the heat of the coal which is usefully employed in making steam. The four smaller areas represent avenues of loss and the size of these areas with the percentage figures which accompany them indicates the possible magnitude of these losses under normal operation. The losses may be much greater when locomotives are in poor condition. In all cases, however, they may vary to a considerable extent depending upon the degree of excellence with which the locomotive is fired and handled.

The ashpan and ashpit losses, the losses represented by the unburned gases and cinders, and those due to the heat in the escaping gases indicate the directions in which efforts to effect savings should be made. The largest of these losses, that due to heat in the gases escaping from the stack, is in large part unavoidable, since these gases must always escape at a temperature near to or somewhat above the temperature of the steam in the boiler. Under service conditions also the loss due to unburned fuel discharged into the ashpan or to cinders and combustible gases discharged through the stack will always take place to some extent. In such losses there is, however, opportunity



100% coal burned in locomotives annually	(1918 est) 150,000,000 tons
70% is applied in making steam	105,000,000 tons
14% goes out of the stack as heat in gases	20,800,000 tons
8% goes out of the stack as cinders	12,000,000 tons
4% goes out of the stack as unburned gases	6,000,000 tons
4% goes into the ashpan and ashpit	6,000,000 tons

(These figures are based upon good performance, which is much better than the average performance of all the locomotives of the country.)

FIG. 1. HEAT DISTRIBUTION FOR THE FIREBOX AND BOILER

for considerable savings. While it is impossible to eliminate entirely any of these losses, each may, through skilful and careful firing and engine operation, be reduced. The total loss from the four sources amounts to 30 per cent of the heat value of the coal fired, and the difference between good and poor practice with a given locomotive represents at least an appreciable percentage of the total coal used. What it means to save one per cent of the total coal used in locomotives has already been pointed out.

The Locomotive

Fig. 2 presents graphically and in somewhat different form the same information which is presented by Fig. 1 together with some additional facts relating to the avenues of use and loss as the steam passes through the engines and the front end of the locomotive. This illustration shows the possible distribution of the heat when coal is being burned at the rate of 70 or 80 pounds per square foot of grate surface per hour. As in Fig. 1 there is shown a 4 per cent ashpan loss, a 14 per cent loss to heat in the stack gases, a 4 per cent loss to unburned gases, and an 8 per cent loss to cinders. The remaining 70 per cent of the heat of the coal is stored in the steam. Of this stored heat, 5 per cent is shown as lost by radiation, 6 per cent goes to the operation of the air pumps, blower, etc., and 59 per cent goes to the cylinders. Of the heat going to the cylinders, a large part, 52 per cent of the original heat of the coal, is exhausted and passes out through the stack. Of the remaining 7 per cent, 1 per cent is used up in overcoming the friction of the locomotive, and 6 per cent is obtained as work at the drawbar.

The losses shown by Fig. 2 as occurring after the heat is stored in the steam are those due to radiation, to steam using devices other than the main cylinders, to the heat of the exhaust steam, and to the heat required to overcome the friction of the locomotive itself.

The radiation losses probably cannot be greatly reduced, and whatever reduction is possible is a matter of design and maintenance in connection with the lagging.

That portion of the heat going into the air pumps and other steam using devices is a loss only in so far as more steam is used in this way than is necessary. The operation of bell ringers, reverse gear, and grate shakers as well as the lighting and heating require the consumption of steam and coal. The estimate that 6 per cent of the heat is

given to air pumps and other steam using devices is a comparatively low average value. Air leaks, particularly in freight service, may greatly increase this loss. The air pumps ordinarily use the greatest amount of steam for auxiliary work and the amount of coal and steam which they use depends very largely upon how well the air brake equipment is maintained. The opportunity for saving here lies in the proper maintenance of all auxiliary apparatus and its careful operation by the enginemen.

The largest heat loss is that of 52 per cent in the steam which is exhausted from the cylinders and passes out through the stack. This exhaust steam, however, does a large amount of useful work in forcing air through the grates and in forcing the gases of combustion through the firebox and boiler. The possibility of reducing this loss is mainly a matter of design, although maintenance and the care with which the throttle and reverse lever are handled are important factors in the problem.

About one per cent of the total heat of the coal or one-seventh of the energy developed in the cylinders is consumed in operating the locomotive itself, or overcoming locomotive friction. The percentage lost as locomotive friction is a serious one since it affects directly the effective work done at the drawbar. Assuming that, in the case given, the locomotive friction loss could be reduced from one per cent to three-fourths of one per cent, then the effective work at the drawbar would be increased from 6 per cent to $6\frac{1}{4}$ per cent; that is, the effective work would be increased about 4 per cent. This would mean that the locomotive could do the same work at the drawbar with a saving of about 4 per cent of its coal. Savings in connection with locomotive friction are largely matters of proper maintenance of the locomotive running parts and of careful lubrication.

The heat losses so far considered are those which to a greater or less extent exist under normal conditions, or with the locomotive in what may be called good operating condition. Most of these losses such as the radiation loss, the loss of heat out of the stack, or the heat which goes to the performance of work necessary to the operation of air pumps or draft apparatus are in part unavoidable. With the locomotive in poor condition, these losses will be larger. In like manner if the locomotive is not skilfully fired and operated, most of these losses will be increased. The opportunity for saving comes in reducing these losses to the lowest possible amounts through better design, better maintenance, and skilful engine operation and firing.

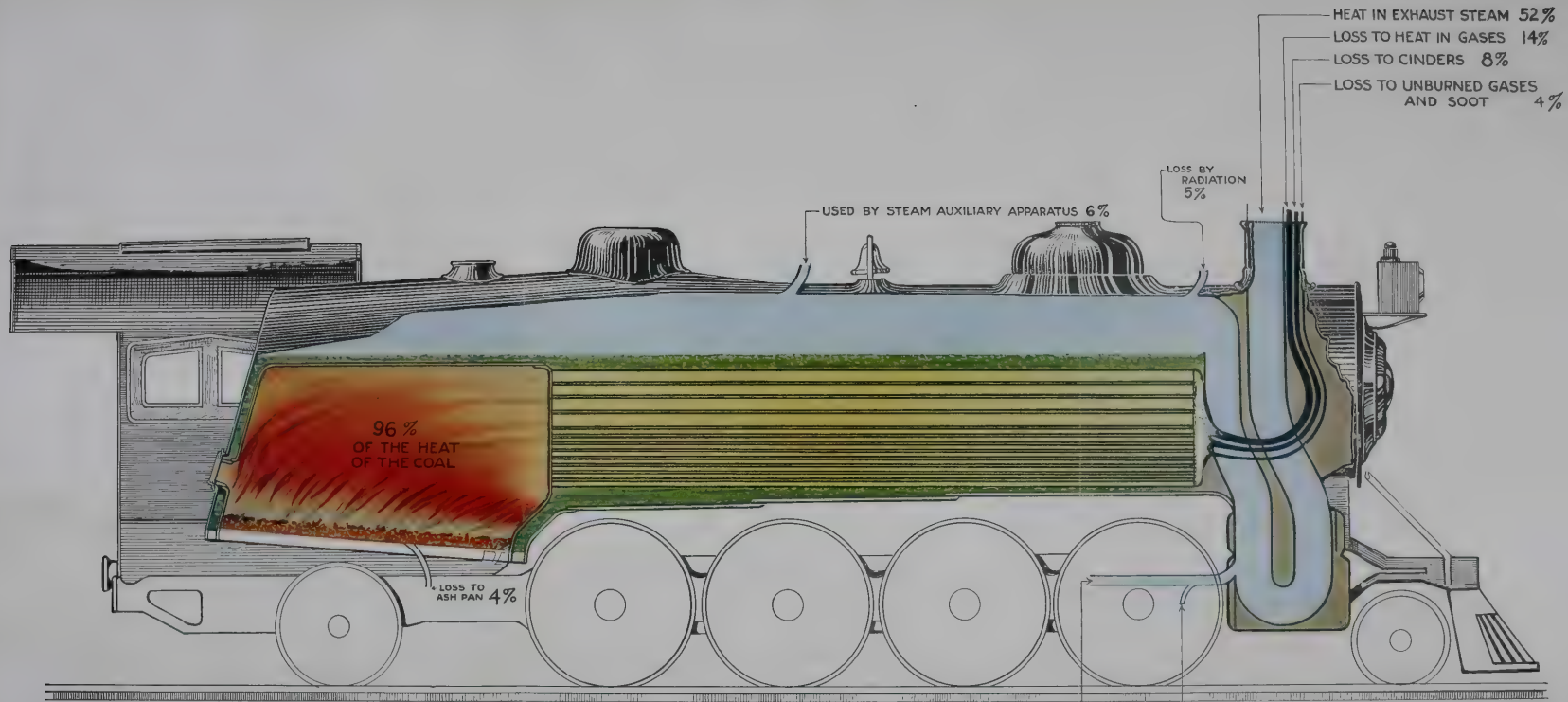


FIG. 2. HEAT DISTRIBUTION IN THE LOCOMOTIVE

Combustion in the firebox liberates heat from the coal.

Combustion is not complete, and all the heat of the coal is not liberated. Cinders and combustible gases escape unburned from the firebox and pass out through the stack.

Some of the heat liberated from the coal is carried out of the stack by the stack gases. Air and coal at a temperature of say 70 degrees F. go into the firebox; the gases which they form come out of the stack at 500 or 600 degrees F. For each ton of coal which goes into the firebox about 12 tons of air also go in and about 13 tons of gases pass out of the stack. It takes some of the heat of the ton of coal to heat these 13 tons of gases from 70 degrees to 600 degrees.

The heat liberated in the firebox, except that which is used to heat the stack gases, passes through the firebox sheets, the boiler tubes, and the superheater units to the water and steam.

Some heat is lost by radiation. This comes from all parts of the locomotive which are warmer than the surrounding air. The most of the heat lost by radiation comes out of the steam.

The heat in the steam is used for auxiliary purposes, is lost as leaks, or goes to the cylinders to do work.

Some coal is lost to the ashpan and ashpit.

Of the heat going to the cylinders a large portion passes out the stack in the exhaust steam. This exhaust steam produces the draft necessary to force into the firebox and through the firebox, boiler, and front end the 12 tons of air and the 13 tons of gases which are moved for each ton of coal fired.

That portion of the heat converted into work in the cylinders moves the locomotive and its train. A portion moves the locomotive and its parts and the remainder becomes work usefully applied in hauling tonnage.

Fig. 2 is shown without a brick arch. Firebox conditions similar to those indicated might be more readily maintained in fireboxes with arches.

Fig. 2 and the successive colored figures are somewhat conventional representations of locomotive firebox conditions. To increase, almost white, heat which often exists in practice cannot be represented satisfactorily with colors. The colorings and details are somewhat exaggerated in the design to emphasize the particular features being illustrated or under discussion.

Sheer Wastes

In addition to the losses already considered, there are certain losses which may be called complete or sheer wastes. Such wastes give no return for the heat lost and are for the most part avoidable. Leaks of steam or hot water as at the mudring or of steam at the piston rod or valve stem packing mean the escape of heat and its complete loss. Steam leaks into the firebox at the superheater header or from the steam pipes mean direct loss of heat and probably a greater loss due to the poor conditions which such leaks bring about in connection with engine performance. Front end air leaks mean a coal loss, and blows past the engine pistons and valves greatly increase the amount of steam required and consequently the amount of coal which must be burned. Considerable steam may be wasted through safety valves. Forty or fifty pounds of coal per minute may be required to furnish steam to discharging safety valves. Frequent and long continued blowing of safety valves means the burning of more coal than is necessary.

In the preceding discussion the percentage of the available energy which is obtained at the drawbar as work has been assumed to be usefully employed. Improper or poor maintenance of cars and car equipment may, however, cause a waste of the power delivered at the drawbar, and therefore may require the consumption of a larger amount of coal than would otherwise be necessary. Sticking brakes, poorly maintained or poorly lubricated journals, or other defects which unnecessarily increase train resistance or cause delays or stops result in a waste of coal. The importance of the loss which results from air line leaks has already been pointed out. Losses of considerable importance may likewise take place in connection with train heating; such losses could be reduced and the comfort of passengers increased by the more general use of thermometers or even of thermostatic control apparatus in passenger coaches. Fuel wastes which may be eliminated through better maintenance of cars and car equipment should not be overlooked by those responsible for this part of the maintenance work.

8. *Summary of Losses.*—A graphical summary of the coal or heat uses and losses which have been discussed is presented as Figs. 3, 4, 5, and 6, each illustration representing the distribution of losses for a different locomotive or for a different set of operating conditions. These performance conditions may be described as ranging from very

good to poor. In all four cases the locomotive is regarded as delivering the same amount of work at the drawbar.

Table 1 lists the ten avenues of use or loss for the heat from the coal fired to the locomotive.

TABLE 1
HEAT USES AND LOSSES WHICH OCCUR ON A LOCOMOTIVE

(a)	1. Heat primarily useful or that which is obtained as work at the drawbar
(b)	Heat used for the purpose of operating the locomotive: 2. By the air pumps and other steam using apparatus 3. As exhaust steam and for the production of draft 4. In overcoming locomotive friction
(c)	Heat lost or wasted due to: 5. Steam leaks to the outside air or from the boiler to the firebox or into the front end. Steam from safety valves, etc. 6. Unburned fuel to the ashpan and ashpit 7. Unburned fuel as cinders 8. Escaping combustible gases 9. Heat in the escaping gases 10. Radiation

All the items listed in Table 1 except that of useful work indicate avenues of possible loss and present opportunities for effecting economies. The percentage of the coal going to the different items will in practice vary widely depending upon the skill and care with which the firing is done and with which the locomotive is handled, upon the kind and condition of the coal, upon the design of the locomotive including its equipment of fuel saving devices, and upon the condition of the locomotive as to maintenance and roundhouse care.

Fig. 3 shows the percentage of heat uses and losses which have already been given in connection with Figs. 1 and 2. The values in the column headed "Estimated Possible Savings" indicate the points at which the greatest opportunities for saving lie, and also indicate roughly the amount of saving which it should be possible to make through improvements, principally in locomotive firing and operation, and through better locomotive maintenance. These estimated possible savings amount to 6 per cent of the total coal fired, and are to be made in connection with six of the different losses which exist.

The coal losses which occur on a given locomotive and the coal savings which can be made are so closely related that a change effecting any one loss generally effects to a greater or less extent most of the other losses. A saving of one per cent of the coal value through the better operation and better maintenance of air pumps and air brake

equipment means that less coal will have to be burned. Less coal burned means less steam necessary to produce draft, and therefore a saving in the exhaust steam is effected. The burning of less coal also means a reduction in the quantity of coal lost in the form of cinders, unburned gases, and heat in the escaping gases. Any improvement, whether in operation or maintenance, which brings about better fire-box conditions will ordinarily effect savings not only in connection

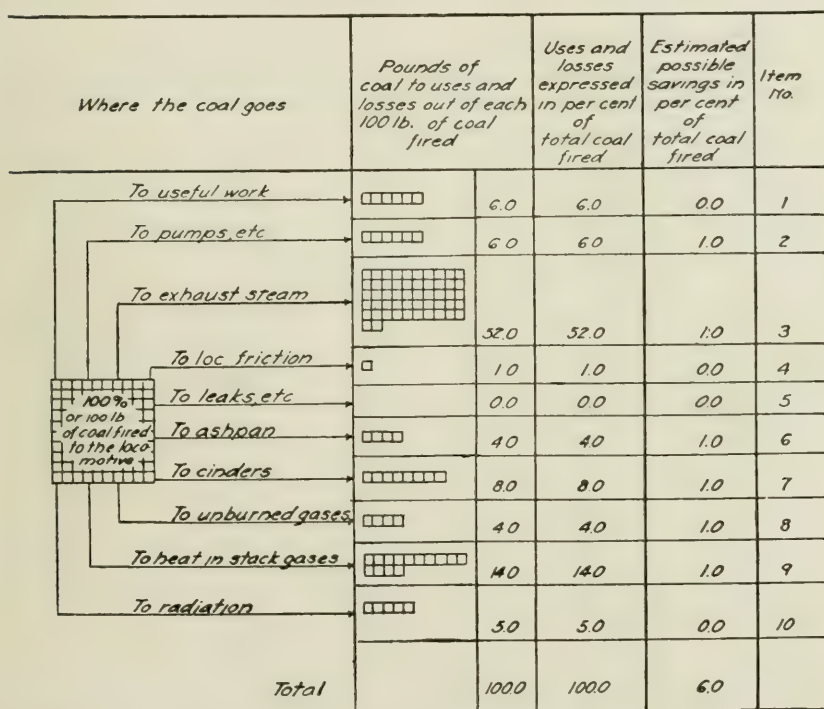


FIG. 3. HEAT AND COAL DISTRIBUTION—LOCOMOTIVE A

Locomotive A is assumed to be a modern locomotive in good average condition, using western bituminous coal and burning from 70 to 80 pounds of coal per square foot of grate surface per hour.

Sixty-five per cent of the heat has been stored in the steam, 5 per cent having been lost by radiation. The efficiency of the boiler is 65 per cent.

Work equivalent to the heat of 6 pounds of coal, or 6 per cent of the total coal, is obtained for each 100 pounds of coal fired. The overall locomotive efficiency is 6 per cent.

Coal savings amounting to 6 per cent of the coal fired should be made by reducing coal uses and losses other than that obtained as useful work at the drawbar.

Each small square in the above diagram represents one pound of coal.

with one loss, but generally in connection with four losses, those to ashpan, to cinders, to unconsumed gases, and to heat in the stack gases.

The percentages given in Fig. 3 refer to average performance on a locomotive in good condition, and the savings here estimated as possible might not be readily obtainable on some locomotives which are in the very best of condition and are being well fired and handled. On

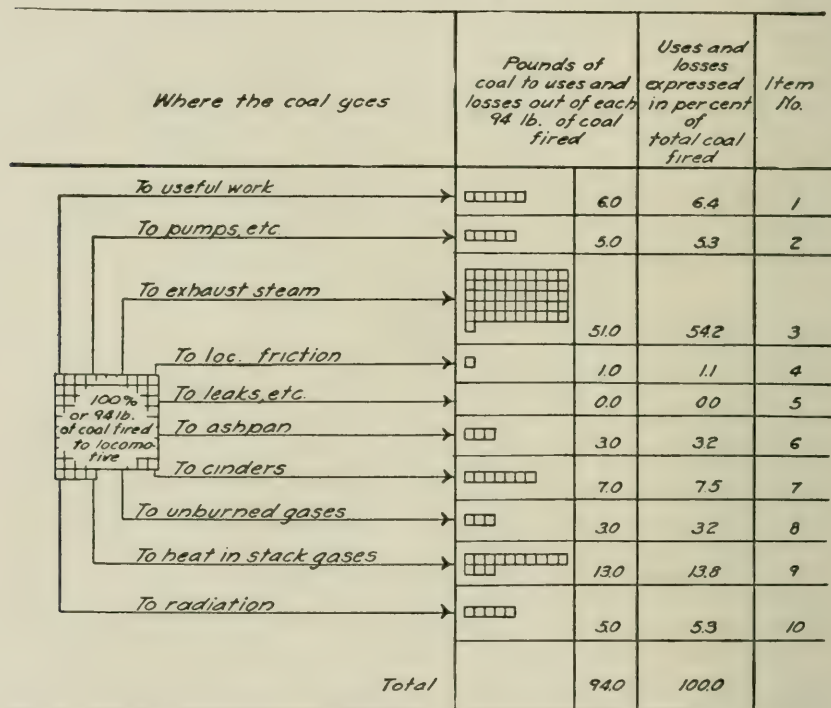


FIG. 4. HEAT AND COAL DISTRIBUTION — LOCOMOTIVE B

Locomotive B is assumed to be in somewhat better condition than locomotive A due to better maintenance and care and is assumed to have been more carefully fired and operated in order to save coal.

Six pounds of coal per 100 pounds fired have been saved as compared with the performance of locomotive A.

Sixty-seven per cent of the heat has been stored in the steam, 5 per cent having been lost by radiation. The boiler efficiency is 67 per cent.

Work equivalent to the heat of 6 pounds of coal, or 6.4 per cent of the total coal, is obtained for each 94 pounds of coal fired. The overall locomotive efficiency is 6.4 per cent.

The diagram shows this saving to have been brought about principally through improvement of combustion conditions and in part through saving steam at pumps, etc., and at the exhaust.

Each small square in the above diagram represents one pound of coal.

the other hand, many locomotives are not in all respects in the best condition and are not fired and handled with the greatest possible care. With many of these locomotives much greater savings would be possible than those indicated by Fig. 3. Fig. 4 indicates the distribution of the coal or heat assuming that the 6 per cent saving indicated as possible by Fig. 3 has been made.

Fuel losses are greatly affected by steam leaks. Direct steam

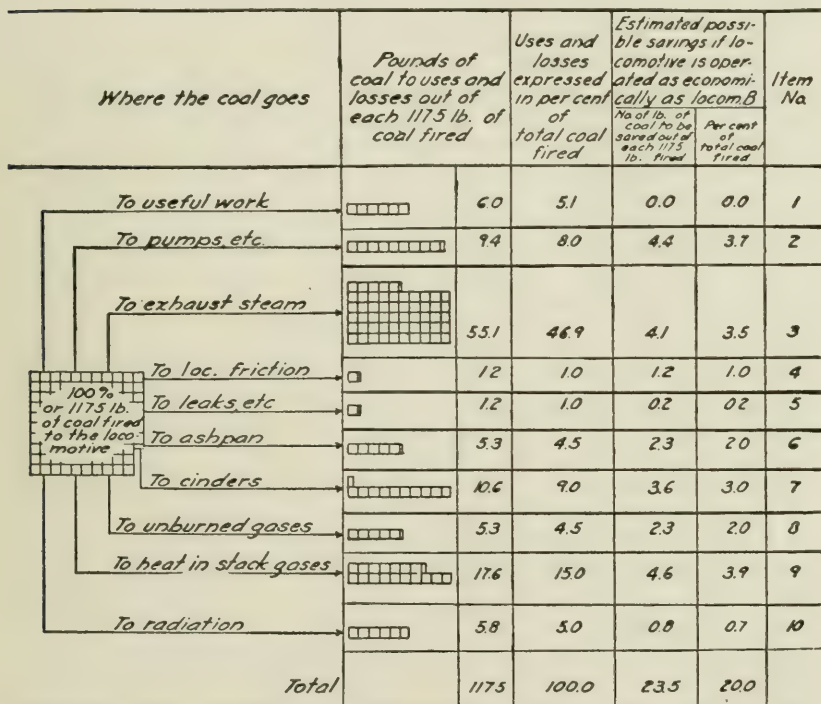


FIG. 5. HEAT AND COAL DISTRIBUTION — LOCOMOTIVE C

Steam leaks, poorer general condition of the locomotive, and less skilful firing and operation are assumed to have caused much less satisfactory performance for locomotive C.

Sixty-two per cent of the heat has been stored in the steam, 5 per cent having been lost by radiation. The boiler efficiency is 62 per cent.

Work equivalent to the heat of 6 pounds of coal, or 5.1 per cent of the total coal, is obtained for each 117.5 pounds of coal fired. The overall locomotive efficiency is 5.1 per cent.

Coal savings ranging from 0.2 to 3.9 per cent of the coal fired are estimated as possible in connection with the uses and losses shown on the diagram. Twenty per cent of the coal of locomotive C would be saved if it were operated as well as locomotive B.

Each small square in the above diagram represents one pound of coal.

leaks to the outside air whether from the boiler or from the cylinders and valve chambers mean a direct loss of coal. Steam leaks into the firebox aside from being a direct loss may occasion a still greater loss through increasing the ashpan, cinder, unburned gas, and heat in gas losses through the resulting poor firebox conditions. Steam leaks past cylinder and valve packings greatly increase the heat loss in the exhaust steam, and by requiring more coal also increase the losses which

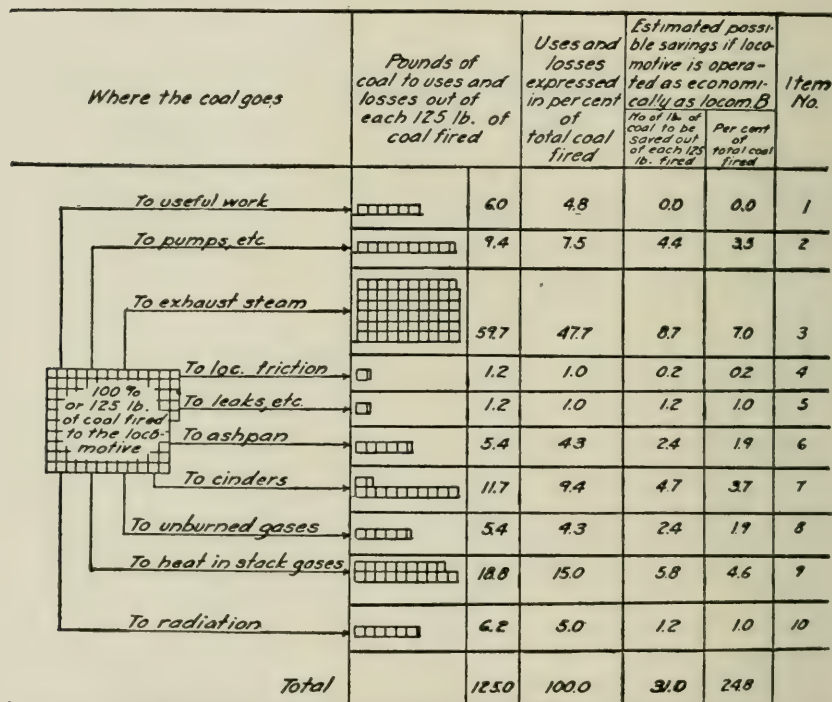


FIG. 6. HEAT AND COAL DISTRIBUTION—LOCOMOTIVE D

A comparatively large loss in the exhaust steam, in leaks, and in poor combustion conditions causes a large coal loss for locomotive D.

Sixty-two per cent of the heat has been stored in the steam, 5 per cent having been lost by radiation. The boiler efficiency is 62 per cent.

Work equivalent to the heat of 6 pounds of coal, or 4.8 per cent of the total coal, is obtained for each 125 pounds of coal fired. The overall locomotive efficiency is 4.8 per cent.

Coal savings ranging from 0.2 to 7.0 per cent of the coal fired are estimated as possible in connection with the uses and losses shown on the diagram. Twenty-four and eight-tenths per cent of the coal of locomotive D will be saved if it is operated as efficiently as locomotive B.

Each small square in the above diagram represents one pound of coal.

take place in connection with the combustion process. Steam leaks or air leaks into the front end also necessitate the use of more steam to produce the draft required, thus materially increasing the exhaust steam loss and so also effecting other losses. The losses just mentioned including direct steam leaks are made evident through the increase in the losses which are listed in Table 1; thus an air leak into the front end or a blow past the cylinder packing increases the exhaust steam loss and in general increases the losses under items 6, 7, 8, and 9.

A steam leak into the front end makes a direct loss, item 5, and in general increases the losses under items 3, 6, 7, 8, and 9. It is well known that leaks to the firebox or cylinder blows may produce losses so great that an engine failure results. In such cases the amount of fuel wasted is, of course, very large.

Fig. 5 indicates the heat distribution where the losses are greater than those shown by Figs. 3 and 4. The pumps and auxiliary apparatus use 8 per cent, and the direct steam losses account for one per cent of the heat of the coal, while the ashpan, cinder, unburned gas, and stack heat losses are all greater. More steam is used in the cylinders under the conditions of Fig. 5 so that the loss through the exhaust is also greater. The direct leak loss and losses arising from it are due to improper maintenance. The increased loss at the pumps and other auxiliary steam using apparatus may be due largely to increased train line air leaks and to poor operation or maintenance of the pumps and other steam using devices. The increased losses in the exhaust steam, the ashpan, the cinders, the unburned gas and the stack heat are likewise probably due in part to less skilful firing and engine operation and in part to poor maintenance of the locomotive. Fig. 5 shows that locomotive C has used 17.5 pounds more coal than locomotive A, and 23.5 pounds more coal than locomotive B in producing the same amount of useful work. If locomotive C were operated with the same economy as locomotive B, a saving of 20 per cent of the fuel of locomotive C would result.

Fig. 6 indicates the heat distribution when there is a somewhat heavier loss through the exhaust steam such as might be caused by bad leaks past the cylinder packing. This illustration shows locomotive D as using 31 pounds of coal more than locomotive B for work equivalent to 6 pounds of coal delivered at the drawbar. The operation of locomotive D with the same economy as locomotive B would mean a saving of practically 25 per cent of the fuel of locomotive D.

As a locomotive approaches its "shopping" time, it probably carries more scale, leaks are more common, packings do not fit so closely, and its general condition is such that coal losses are greater than would be the case if the locomotive were kept in better condition throughout the period between shoppings.

Important coal savings which can be considered as immediately possible are to be made for the most part in two ways, by improving the mechanical condition of locomotives through better care and maintenance and by exercising greater care in the firing and operation of the locomotive while in service. For a given locomotive the total possible saving can be effected only when attention is given to both these matters, that is, when the engine is both better cared for and better handled. With locomotives in good condition, the total possible savings are comparatively small, but more careful engine operation and more skilful firing will even in this case yield results worth while. With locomotives in less satisfactory condition, the total possible savings become greater and in general the greater part of such savings can be effected through better maintenance and care.

Table 1 and Figs. 3, 4, 5, and 6 show nine ways in which coal may be used or wasted other than in producing useful work at the drawbar. The careful consideration of these avenues of waste makes it evident that somewhat better maintenance and roundhouse care and somewhat better firing and operation should result in an average coal saving on all the railroads of the country which can be conservatively estimated as at least 6 per cent of the total coal fired.

Certain improvements which may be considered matters of design rather than of maintenance may often be adopted to aid in reducing the amount of coal or steam used. Front end arrangements, grates or other firebox parts, and cylinder or other packings indicate points at which through better design the coal uses and losses which have been discussed may be decreased.

The values for "Estimated Possible Savings" shown in the preceding diagrams are not intended to indicate the possible savings through the installation of some of the more important fuel saving devices such as the superheater. It has already been pointed out that since the installation of such devices usually requires executive action, they probably cannot be generally adopted and installed as emergency matters. The brick arch can, however, often be added to existing equipment with comparatively little loss of time and without great

expense. On account of the great reduction in fuel losses which can often be made through the use of the more important fuel saving devices, their more extended use under present conditions is to be urged.

Since the possibility for economy through the employment of these means is great, it is proper to point out the extent of the fuel saving which may be expected upon locomotives equipped with such devices as compared with similar locomotives without these devices. The report of the American Railway Master Mechanics' Association Committee on Superheater Locomotives for the year 1916* contains the following statement concerning economies:

"In view of the many complete reports which have already been rendered on tests covering the economies effected through the application of superheater, and superheater and brick arch, your committee does not believe it necessary to publish further data in this report. However, on a conservative basis, it is felt that an economy of fifteen to twenty-five per cent in fuel and twenty to thirty per cent in water consumption can be expected in every-day operation through use of the superheater and brick arch. Numerous tests have shown greater economies.

"On a number of railroads the application of superheaters has reduced the time of freight trains on the road ten to fifteen per cent and eliminated one stop for coal and two stops for water over one freight engine division."

Test data from various sources covering both road and laboratory tests indicate that locomotives equipped with superheaters burn from 6 per cent to 30 per cent less coal, for the same work, than similar locomotives not equipped with superheaters. In like manner data relating to the brick arch indicate possible coal savings ranging from 5 per cent to 12 per cent.

Table 2 presents information concerning fuel savings which have been effected through the use of the superheater and the brick arch.

While it may not always be possible under the varying conditions of road service to obtain as great savings as those indicated in Table 2, a very great opportunity for effecting fuel economy is presented through the more general use of the important fuel saving devices. The total saving of locomotive fuel which may be accomplished in this way is, of course, dependent upon the extent to which old locomotives may be supplied with such devices and the extent to which new locomotives fitted with such devices may be employed.

*Proceedings American Railway Master Mechanics' Association, Vol. 49, p. 131, 1916.

TABLE 2
 COAL SAVING THROUGH THE USE OF THE SUPERHEATER
 AND THE BRICK ARCH

Coal Saving Due to the Superheater Per Cent	Source of Information	Coal Saving Due to the Brick Arch Per Cent	Source of Information
6 to 17	Publication 126 Carnegie Institution of Washington	5 to 8	Report of Coatsville Tests, W. F. M. Goss
20 to 30	A. R. M. M. Ass'n. Proceedings, 1911	12	Report of Coatsville Tests, W. F. M. Goss
12.3 to 29.8	Penn. R. R. Co. Test Dept., Bulletin No. 21	6 to 8	Penn. R. R. Co. Test Dept., Bulletin No. 30
26.8	A. R. M. M. Ass'n. Proceedings, 1914	12 to 13	Penn. R. R. Co. Test Dept., Bulletin No. 6

IV. HOW TO SAVE COAL

9. *Means to be Employed.*—The character and extent of the losses which may occur in transporting, storing, and handling coal for locomotive use, the losses which may occur through terminal, roundhouse, and road delays, when firing, cleaning and turning locomotives, and the losses which occur in connection with the burning of the fuel and the use of the steam have been summarized and discussed. The effort has also been made to show in what connection it is possible to effect fuel economy and to indicate approximately the magnitude of the possible saving. It is the purpose of the present chapter to point out how these savings can be made and to indicate the officials or employees who would assume the responsibility for making them.

Coal can be saved in connection with :

- (1) The selection, distribution, and storage of coal
- (2) Roundhouse and shop equipment and the care of locomotives
- (3) Locomotive design
- (4) Locomotive operation

It should further be emphasized that only through coöperation upon the part of all who are in any way concerned with locomotive fuel can the highest degree of economy be attained.

In addition to the four avenues of economy mentioned there are certain matters of organization or operation which affect fuel economy in a broad sense or which under present conditions should be adopted in the effort to save coal. A properly organized fuel department should do much to prevent coal wastes. This department may have charge of the purchase, inspection, and distribution of fuel, exercise supervision looking to its economical use, prepare and make use of records relating to fuel consumption and standards of performance, and have charge of such educational work as is to be carried on for the purpose of promoting fuel economy. The establishment of proper standards of performance with regard to fuel consumption together with thorough going supervision by road foremen of engines or fuel supervisors are of the greatest importance in the matter of coal savings. Managing officials may find it possible to save coal through the

rearrangement of schedules or through a reduction in the weight or speed of some of the heavier and faster trains. Careful consideration may show that certain locomotives in freight service are not operating economically because of overloading. Heavy loading of locomotives is being relied upon at the present time to move large amounts of traffic. The traffic gain may be of much greater importance than the amount of fuel wasted. Where such wastes occur, however, they should be recognized and prevented if possible. On the other hand, the elimination of some fast freight runs and the handling of greater tonnage per train at slower speed may be a possible means of saving coal.

10. *Selection, Distribution and Storage of Coal.*—Certain coal savings can be effected through the exercise of care in selecting the kind or size of coal best fitted for the service or for the locomotives in which it is to be used. Coal can be saved by preventing the actual loss of coal during its distribution as from cars, tenders and coal chutes, and by preventing fire loss or deterioration in storage coal. The selection, distribution, and storage of coal and their relation to losses and possible savings are discussed in this circular in the chapter on coal.

11. *Roundhouse and Shop Equipment and the Care of Locomotives.*—Coal can be saved by improving shop and roundhouse facilities for the maintenance and care of locomotives. While it is difficult to estimate the exact extent of the coal savings to be effected through improved roundhouse and shop facilities, it is known that a locomotive in poor condition mechanically or one in which scale, soot and leaks have become serious may use 10 to 40 per cent more coal than a locomotive in good condition. Modern facilities properly operated should help maintain all locomotives in better average condition. Good coal chutes, ashpits, inspection pits, hot water washing and filling systems, and good general roundhouse equipment and organization make it possible to care for locomotives properly within a reasonable time, prevent the turning of engines without sufficient cleaning or maintenance work, and thus prevent the waste of coal which results from dirty, leaky, and poorly maintained locomotives.

Good shop facilities are also important in the matter of saving coal through their relation to locomotive maintenance. Every piece

of poor or careless work whether in connection with the boiler parts, the engine parts, or the auxiliary apparatus means a loss of coal later through less satisfactory locomotive performance. Shop men and shop officials should recognize the responsibility they bear in matters of this kind. Leaks mean losses which are often repeated day after day. Ill-fitting parts mean loss of power and of coal. Good workmanship always means fuel economy.

Whatever may be the shop and roundhouse facilities available it should be remembered by the roundhouse forces that locomotive fuel economy is very largely dependent upon how well and how thoroughly locomotives are cleaned and cared for between trips. The following up of enginemen's reports and thorough inspection make it possible for work upon the locomotive to be most effective. Careful repairs of leaks, of grates, of arches, and of locomotive running parts mean fuel economy. Boilers should be properly washed and kept free from heavy scale. Leaks, which are the cause of many of the most serious fuel losses, are often due to scale and mud. Tubes, tube sheets and superheater flues and units should be cleaned of soot and ashes. Soot and scale often cause very large fuel losses; their removal means fuel saved. To send out a locomotive in poor condition means a serious waste of coal.

12. *Locomotive Design*.—Executive and motive power officials can save coal through attention to matters of locomotive design and equipment. The fact that difficulties concerning expenditures of time and money are involved ought not to prevent the careful consideration of such matters. The saving of coal which can be effected along these lines is most important.

It may be possible to save coal:

By using grates and grate bars better suited to the kind and size of coal.

By providing ash pans with greater openings for the admission of air.

By making the front end arrangement more economical in the use of exhaust steam or in utilizing the heat generated in the firebox.

By making packing and lubrication devices more effective in reducing friction.

The installation of superheaters and brick arches upon existing equipment should receive careful consideration and installations should be made as rapidly as possible where warranted. Under present conditions the more general installation of important fuel saving devices of this kind is advisable even though the financial savings may be slight.

While engineers and firemen are not primarily responsible for matters of locomotive maintenance and design, they can aid materially by making careful and specific reports about all matters requiring attention. Many defects such as leaks can be discovered only by engineers and firemen while the locomotive is at work on the road, and their coöperation in reporting trouble is essential to good maintenance. Under the common practice of pooling engines, the incentive to be scrupulous in this regard is not so great as under the old plan, but the responsibility nevertheless remains.

Fuel Consumption while not Hauling Trains

13. *Locomotive Operation.*—It has already been pointed out that about one-fifth of all locomotive fuel is burned during the time when the locomotive is not hauling trains.

Yardmasters can save coal by delivering engines quickly to the roundhouse and thereby cutting down the time during which fires must be kept burning.

Fires kept up during delays at ashpits mean a waste of coal, and the elimination of such delays may be the means of important fuel savings.

Coal can be saved through economical methods of kindling fires and through the use of economical kindling material. If considerable coal falls through the grates when building fires, it should be saved and not allowed to become mixed with the ash.

When fires are maintained in the house, coal can be saved by covering the stacks to hold the fire and retain the heat. A light metal cover having an adjustable slide which may be opened sufficiently to permit the emission of condensed vapors and gases created when the locomotive is standing with banked fires can be made very cheaply.

Coal can be saved through the coöperation of roundhouse and transportation forces in the matter of calling engines, thus preventing their standing under steam longer than is necessary.

Yardmasters, dispatchers, and trainmen can save coal through

assisting in the elimination of yard and other terminal delays. Locomotives in readiness to handle trains are burning coal rapidly no matter how carefully the enginemen may handle them.

While engines are standing at meeting points or on sidings, fires must be maintained. A large amount of fuel is burned under such circumstances. Transportation forces can effect a substantial coal saving by eliminating as large a part of these delays as possible.

Every stop on the road means the consumption of considerable coal. Every unnecessary stop means a waste of coal. Transportation men, trainmen, and enginemen should all assist in preventing unnecessary stops.

Transportation employes should appreciate that their branch of the service offers important opportunities for the saving of coal. Through action on their part that portion of the fuel now being burned on locomotives not actually used in hauling trains may be materially diminished, and a coal saving of great importance accomplished.

Theory of Combustion

There are three factors involved in the process of combustion:—

- (1) There must be fuel
- (2) There must be oxygen
- (3) There must be an ignition temperature

Thus stated it would seem to be a simple matter, but effective combustion, under the conditions which exist in the locomotive firebox, presents problems which are more complex and difficult than those found in the stationary plant.

The essential constituents of coal, that is, the combustible or heat-producing substances, are carbon and hydrogen. The mineral matter and the moisture constitute a non-burnable portion and comprise a very considerable part, approximately 25 per cent, of the average bituminous coal.

In the process of combustion, every particle of the actual combustible material must be supplied with an exact and definite quantity of oxygen; otherwise the burning process does not take place or the process is incomplete.

The carrier of oxygen is air, but air is not all oxygen, four-fifths of its volume being nitrogen. Nitrogen is an inert gas which in no way contributes to the process of combustion but rather retards it through

its diluting effect which makes the process of complete and quick mixing of oxygen with the fuel more difficult.

Because the locomotive firebox is small the rapidity of combustion is of vital importance. The rapidity of combustion depends upon two factors: the completeness of mixture of air with combustible gases, and the temperature. If the fuel mixture is as intimate as is found in a gasoline engine cylinder, the combustion proceeds with explosive rapidity, even though the gases are surrounded by cold surfaces. The high temperature of gases alone without good mixing of air will not of itself produce rapid combustion; the more necessary factor is intimate mixture of gases at the ignition temperature. To increase temperatures above the ignition point tends to accelerate the process. Combustion attains the greatest rapidity with perfect mixtures at the highest temperature. Under ordinary conditions in the locomotive firebox the temperature is high enough to produce rapid combustion, provided the mixing is complete.

The average bituminous coal contains approximately 75 per cent of actual combustible material, about half of which must burn as volatile matter in the combustion space. The other half, or possibly about 40 per cent, is in the form of fixed carbon, which burns nearly completely on the grate. The volatile part of the combustible, which is driven from the coal and must be burned in the combustion space, consists of complex gases which are hard to burn. On the other hand, the fixed carbon remaining on the grate, when burning, produces gas which is simple and is easy to burn. The rate at which air is forced through the fuel bed controls the rate of combustion of the coal. The completeness of combustion of the gases above the fuel bed depends upon the air furnished above the fuel bed, either through the door, staybolt openings, or holes in the fire. In locomotive practice a large part of this supplementary air must enter through the holes in the fire, the intense pulsating draft requiring relatively small holes to supply this air. It is essential to keep an even firebed without visible holes or black spots in order to prevent an excess of air being drawn through the holes in the fuel bed. When burning coal at 60 pounds per square foot of grate per hour, free openings for air from two to four per cent of the grate area will supply ample air for combustion of the gases above the fuel bed. The most skilful firing is none too good to maintain an even bed which will restrict the free air openings below the figures given.

With regard to the volatile portion of the fuel, most of it is given off in a few seconds after the coal reaches the fuel bed. The heavier tar-like constituents are all driven off by the time the coal has attained a dull red heat. The volatile matter from the coal is a mixture of complex gases requiring a very large amount of air for complete combustion. Some of the gases take ten times their own volume of air and other gases as much as one hundred times to produce complete combustion. The composition of these gases depends upon the conditions under which combustion proceeds. If there is a lack of oxygen, these complex gases will be rapidly decomposed by the high temperature, with the ultimate product of carbon in the form of soot, hydrogen, and carbon monoxide. Probably 95 per cent of this carbon formation takes place within the first foot above the fuel bed. In the absence of oxygen, extremely high temperatures accelerate the breaking down of the heavy hydrocarbons into soot near the fuel bed. One reason why locomotive firing requires skill is that the conditions giving high economy are not definitely controllable by the fireman. Immediately after firing green coal on a uniformly level firebed the small holes are made smaller just at the time when more air is needed, and these holes grow larger and deliver an increasing amount of air just when the fire requires a decreasing supply of air. The only way to approximate a satisfactory condition is to make the charges and firing intervals very small so that extreme conditions do not depart materially from average conditions of air supply.

For efficient combustion the following conditions must be satisfied:

- (1) Fuel and air must be admitted in as nearly a uniform manner as possible.
- (2) A proper distribution and thorough mixing of the air with the combustible gases in the firebox must take place.
- (3) A sufficiently high and uniform firebox temperature must be maintained.

Fuel Consumption while Hauling Trains

Four-fifths of all locomotive fuel are used while the locomotive is in operation actually hauling trains. For the year 1918 this will amount to about 120,000,000 tons of coal. The large amount of coal involved adds emphasis to the desirability of employing any means

which may be available to effect greater economy in the use of fuel in locomotives during the time they are performing useful work. Since locomotives are directly under the charge of the engineer and fireman at this time, the responsibility lies largely with them.

Firing instructions both printed and verbal are commonly based upon the assumption that the locomotive is in good condition. While losses due to defects in design and improper maintenance may be great, engineers and firemen should recognize that, with any locomotive, whatever its general condition, the difference between careful and skilful operation and firing, and poor and indifferent operation may easily account for five or ten per cent of the coal required to perform a given amount of work.

Firing Instructions

The principal purpose of firing instructions is to help to reduce some or all the fuel losses which have been considered in the section on "The Distribution of the Heat Generated in the Firebox" and which are listed in Table 1, page 20. In connection with the process of combustion the firing instructions aim to prevent loss by showing how the three conditions necessary to satisfactory combustion may be brought about (see "Theory of Combustion," page 35).

Instructions regarding level firing and the avoidance of banks, holes and clinkers, and regarding door control, blower operation, and grate operation relate to the supplying of the proper amount of air and the thorough admixture of this air with the burning fuel. Instructions relating to firing at a uniform rate, to spreading the coal, and to closing the firedoor are largely aimed at securing a sufficiently high and uniform firebox temperature.

A level, bright fire should be maintained. In general also the fire should be as light as is consistent with the work which the locomotive is doing and with the character of the fuel being used. Certain precautions are to be observed in maintaining a light, bright, and level fire. Large lumps of coal should not be fired; they tend to make the fire uneven. All large lumps should be broken into pieces not larger than three or four inches.

Apply fresh coal to the parts of the fire which are the brightest and thinnest, that is, where the coal is needed most to keep the fire level and uniformly bright.



FIG. 7. THE UNIFORM FIRE

The condition here represented shows the admission of enough and not too much air. With the grates and draft apparatus in proper condition, a level and uniform firebed permits air to enter without undue obstruction over the entire grate surface and at the same time prevents cold air from entering through holes or thin spots.

With a light, level and bright fire most of the air supply enters the firebox through a uniform firebed. The firebed being uniform, without holes, clinkers, or banks, the air enters in many small streams equally distributed over the entire grate surface. Every part of the fuel bed and of the gases just above the fuel bed has its share of the uniformly distributed and finely divided air streams which are entering through the grates.

High and uniform firebox temperatures result from a proper air supply and a good mixture and most of the coal and gases burn before they can escape from the firebox. High firebox temperatures insure the burning of combustible gases which with lower firebox temperatures escape without giving up their heat.

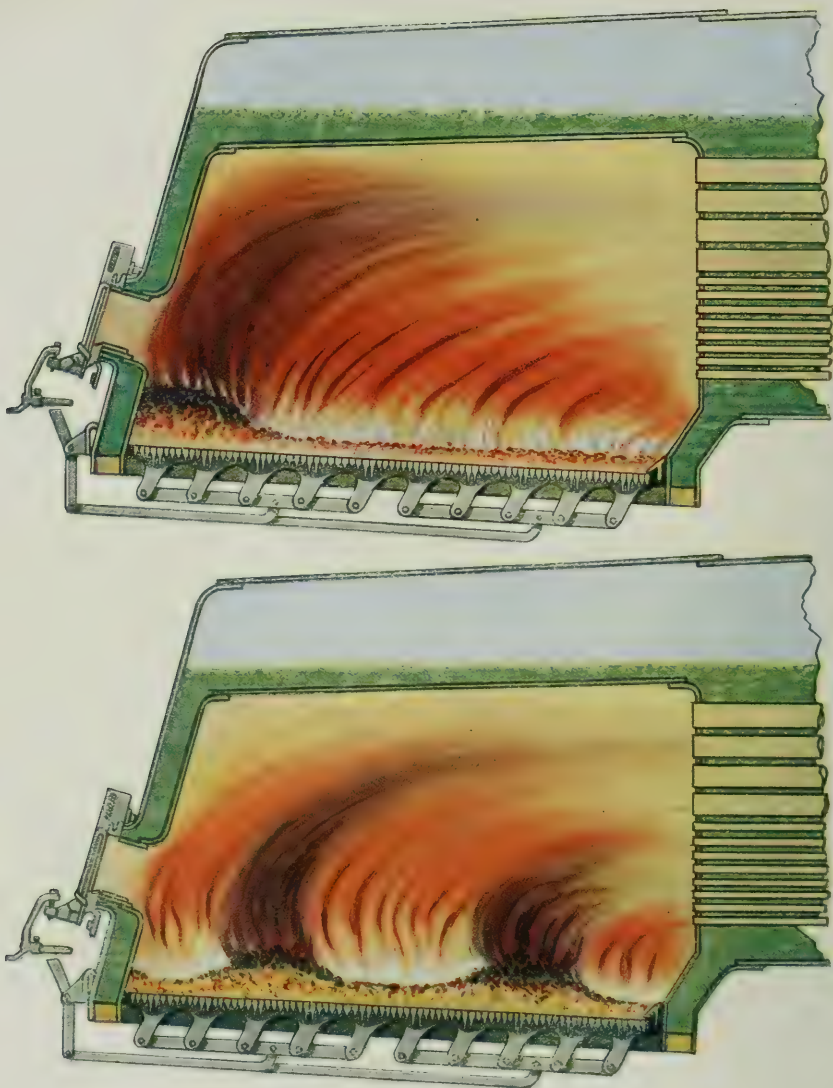


FIG. 8. BANKS IN THE FIRE

The condition here represented shows the results of not enough air or of too much air. Banks may restrict the air supply to such an extent that there is not enough air to insure combustion. Even though large quantities of air may enter through the thinner parts of the fire or through the fire door, the combustible gases arising from the banks may not receive a sufficient supply of air before they escape from the firebox. The firebox may be receiving too much air and still not burn the coal because of the poor mixing.

Above the thinner parts of the fire there may be more air than is needed to burn the fuel with which it comes in contact. This surplus air does not assist in the combustion process, but reduces the firebox temperature and carries off heat through the stack.

Where the coal and gases are heaviest the incoming air supply is least, and neither the incoming air nor the gases arising from the fuel are sufficiently divided into numerous well distributed small streams to permit easy and rapid mixing. Gases arising from the fuel bed reach the flues in a very short time and mixing must be rapid.

The banks of green coal and the smoky gas arising from them tend to cool the firebox as a whole. Some parts of the fire burn much more brightly than others and the temperature throughout the firebox is not uniform. Smoke and unburned gases result from this condition.



FIG. 9. HOLES IN THE FIRE

When holes occur in the firebed the result is too much air in parts of the combustion chamber and not enough air in others.

Holes permit too much air to enter the firebox for the amount of coal which is being burned where the holes exist. The air coming through the hole is in a comparatively solid stream, and where this air comes through there is little fuel to burn. At points where there is fuel on the grate not enough air is coming through, and the opportunity for good mixing is lost.

The large volume of cold air coming through the hole cools that part of the firebox and combustion in other parts of the firebox is retarded.

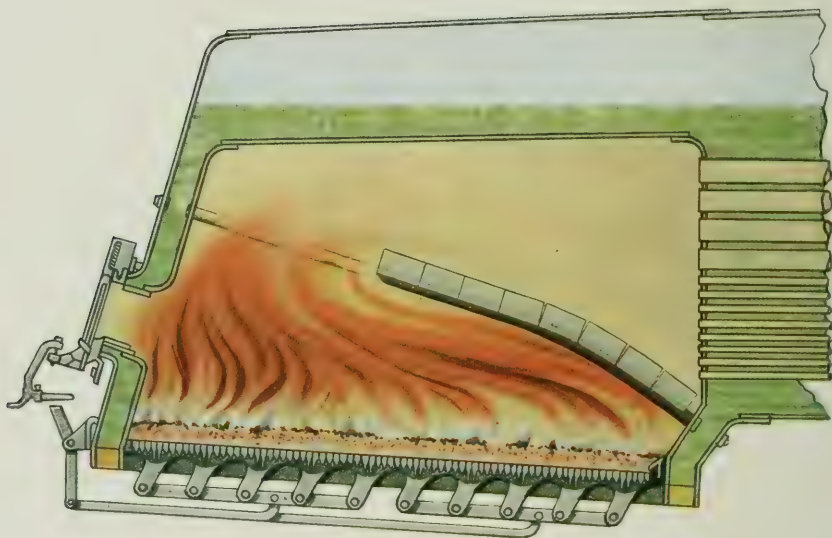


FIG. 10. THE UNIFORM FIRE

This figure is similar to the longitudinal section of Fig. 7 but shows a firebox equipped with the brick arch. Both figures are intended to show practically the same combustion conditions.

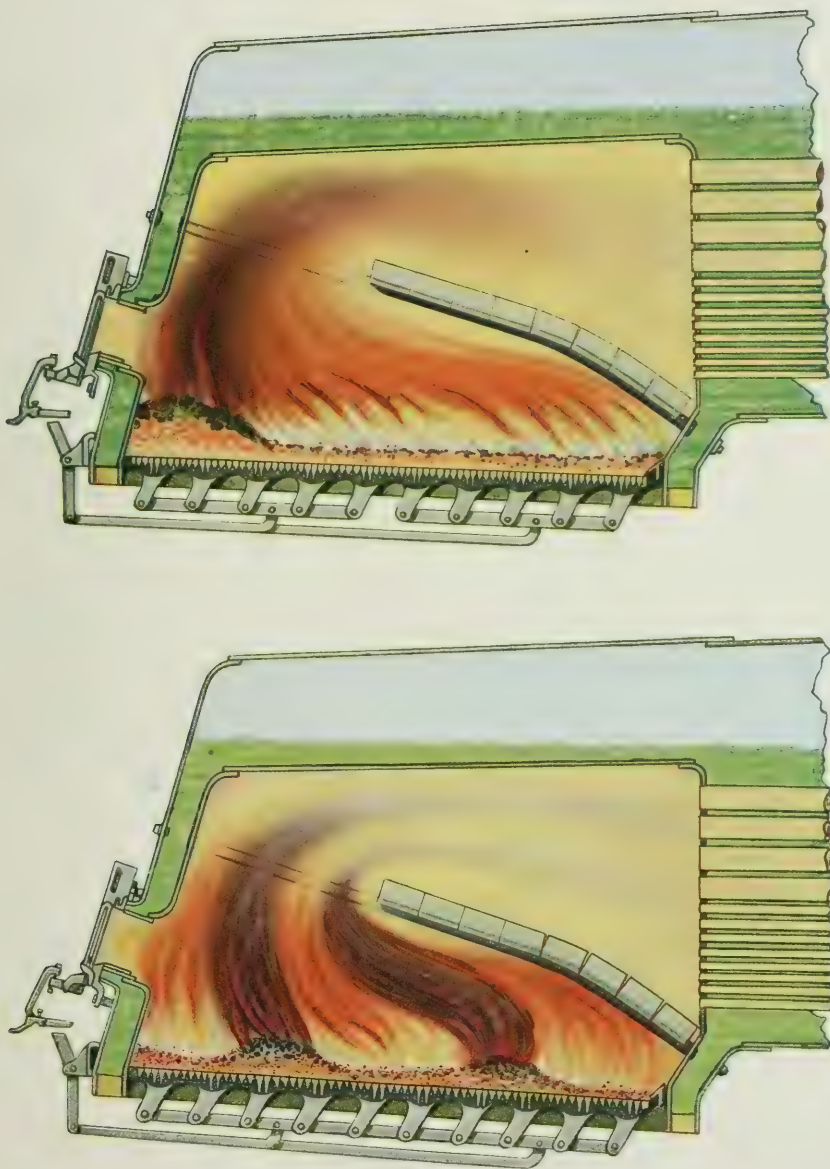


FIG. 11. BANKS IN THE FIRE

This figure is similar to Fig. 8 but shows fireboxes equipped with brick arches. The combustion conditions shown are intended to be practically the same as in Fig. 8, with the dark bands arising from the banks fading out to a somewhat greater extent before reaching the flues. The intention is to show similar combustion conditions rather than the effect of the arch.

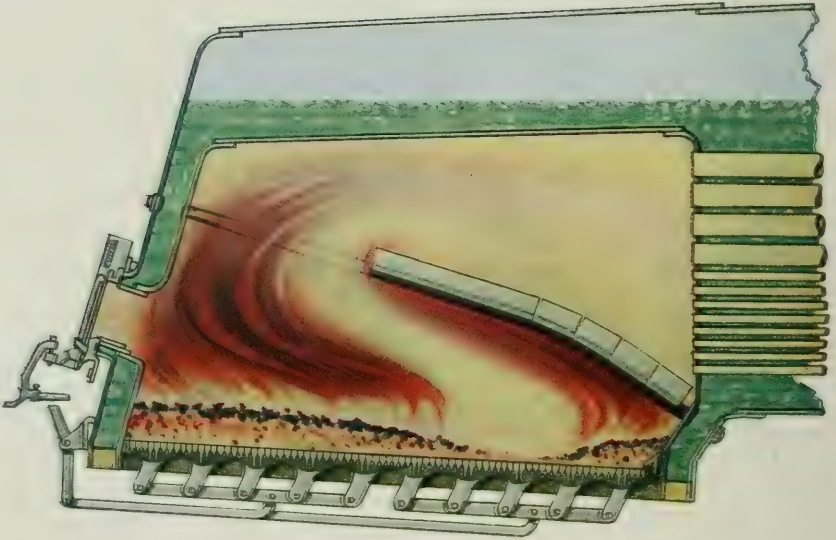


FIG. 12. HOLES IN THE FIRE

This figure is similar to Fig. 9 but shows a firebox equipped with the brick arch. The combustion conditions shown are intended to be practically the same as in Fig. 9 with combustion somewhat better as the gases approach the flues above the arch. The intention is to show similar combustion conditions rather than the effect of the arch.

Fire the coal in small amounts and at regular intervals. One or two shovelful at a firing should ordinarily give the best results. With large fireboxes and high rates of combustion it is often found necessary to apply from three to five shovelful. In any case each shovelful should be spread to that part of the fire where it is most needed to keep the firebed level and to keep the fire as a whole as bright as possible.

Large amounts of coal applied at one firing give off so large a volume of gases that they cannot all be burned before escaping from the firebox; consequently firebox temperatures are lowered, and the air supply through the grate is restricted or broken up into uneven streams. The result is poor combustion and coal loss. Proper mixture of air and fuel, and sufficiently high firebox temperatures produce good firebox conditions. Uniformity in the firing of coal, that is, the firing of small amounts at regular intervals, promotes these conditions.

Firing instructions concerning the spreading of the coal, cross firing, and firing slightly heavier next the firebox sheets to prevent excessive air entering along the sides and ends are intended, first, to help in securing a sufficient but not too great air supply through the fuel bed, and secondly, to insure the mixing of the air thoroughly with the burning fuel. The fuel bed being uniform and of equal thickness throughout, the air will come through it in a uniform manner and so be more or less thoroughly mixed both with the fuel burning on the grate and with the burning gases arising from the fuel bed.

Fig. 7 illustrates a level uniform fire in which a uniform supply of air is passing through the fuel bed, good admixture of air, fuel and gases is taking place, and a high firebox temperature is being maintained. These three conditions result in practically complete combustion and in the greatest possible fuel economy.

Fig. 8 shows firebeds in which banks have been permitted to form either because of heavy firing under the firedoor or because of uneven firing on other parts of the grate. Fig. 9 shows a hole or spot in the fire. Firebeds in which bad clinkers have formed constitute another example of poor firing conditions. Banks, holes, and clinkers all tend to interfere with the uniform flow of air through the fuel bed. Banks and clinkers restrict the flow of air through parts of the bed and accelerate it through other parts. Holes permit large amounts of cold air to flow through them and retard the flow of air through other parts of the fuel bed. Undue lack of uniformity in the fuel bed interferes

with a uniform supply of air, prevents the proper mixing of air and fuel, and tends to lower the temperature of the firebox.

Figs. 10, 11 and 12 present illustrations similar to Figs. 8, 9 and 10, except for the addition of the brick arch. In general, it may be said that it should be easier to maintain good firebox conditions where there is a brick arch and that the bad effects due to banks or holes will be reduced through the action of the arch. The arch produces a much longer average path for the gas to travel from the surface of the firebed to the flues, thus permitting and assisting in a more intimate mixture of the air with the burning gases. The hot arch brick also assists in maintaining a uniform temperature in the firebox. In all the figures the attempt has been made to illustrate certain combustion conditions as related to air supply, air mixture and firebox temperature, and to emphasize the importance of maintaining proper conditions in these respects irrespective of any particular firebox or type of locomotive.

Care should be exercised in shaking grates, the purpose of which operation should be to remove such ash and clinker as may be necessary in order to admit sufficient air but to avoid disturbing the fuel bed so much that holes or additional clinker may be formed. Preferably the grates should be shaken when the locomotive is standing, since holes are likely to result from shaking the grates when running. Many western bituminous coals such as those from Illinois, Indiana and western Kentucky cannot be satisfactorily burned without frequent shaking of the grates. Some eastern coals may be burned with practically no shaking of the grates.

The firedoor should, in general, be closed immediately after each shovelful of coal is fired. This practice prevents an improper air supply, which cannot properly mix with the burning gases and helps maintain a uniform firebox temperature. When the firedoor is wide open a large volume of cold air rushes into the firebox. This cold air lowers the firebox temperature and, being in one large stream, does not readily become mixed with the gases arising from the fuel bed. Too much air may be supplied through the firedoor under almost all firing conditions.

Immediately after a shovelful of coal is thrown on the fire, the gases arising from that coal require more air above the fuel bed than is otherwise needed. Leaving the firedoor on the latch is sometimes advantageous at this time since it allows a certain amount of air to

enter. In general, however, the ashpan openings, the grate openings, and the condition of the firebed are such that the greater part of the air required for combustion is drawn through the grates and the opening or partial opening of the firedoor to supply air rendered unnecessary. In all cases the instructions regarding the firedoor are aimed at the proper air supply, the proper mixing, and the maintenance of a high firebox temperature.

The blower should not be so used as to draw an unnecessarily large amount of air through the firebox. The throttle should not be so operated as to disturb the firebed and the slipping of drivers should be avoided since the firebed is disturbed through the violent action resulting from the exhaust steam.

The waste of steam through the safety valve should be avoided at all times. Careful attention to the handling of the fire at the time of a stop or when standing or drifting will prevent blowing off and wasting fuel.

Careful attention to the handling of the injectors will save coal in several ways. Waste of steam through safety valves may be prevented through the use of the injector. The water level in the boiler should never be so high as to cause water or very moist steam to be carried over to the superheater or to the cylinders. A very serious fuel loss may occur from this cause. In general the injectors should feed the boiler at a fairly uniform rate. It is often possible to make firebox conditions more nearly uniform and more satisfactory through the operation or regulation of the injectors. When the demand upon the locomotive is light, the operation of the injectors makes the demand upon the firebox somewhat heavier; and when the demand upon the locomotive is heavy, a reduction in the amount of water supplied makes the demand upon the firebox lighter than would otherwise be the case. The injectors should feed the water required by the boiler in such manner as to assist in maintaining uniform and satisfactory firebox conditions and they should not be so handled as to occasion direct loss of steam through the safety valves, or to cause priming.

The reverse lever and throttle should always be so handled as to use the minimum amount of steam. The following extracts concerning throttle opening and reverse lever control are taken from the instructions concerning fuel economy which have been adopted as recommended practice by the American Railway Master Mechanics' Association.*

* Proceedings of the American Railway Master Mechanics' Association, Vol. 49, pp. 753, 755, 1916.

“The locomotive should be operated with a full throttle opening (except when starting or drifting) when the cut-off is 25 per cent of the stroke, or greater; but if 25 per cent cut-off with full throttle gives more power or speed than is needed, the reverse lever should be left at 25 per cent cut-off and the throttle partly closed as necessary. With locomotives using superheated steam it is well to use 15 per cent cut-off instead of 25 per cent, as mentioned.

“Superheater locomotives should be operated with a full throttle opening and reverse-lever control, as far as service conditions will permit, the exceptions being: When starting a train, when using a very small quantity of steam, and when drifting.”

The careful handling of the throttle and reverse lever saves steam at the cylinders and also makes it possible for the fireman to do his work more easily and with a greater saving of fuel in the firebox.

Certain other firing precautions relating to injector operation or firing in anticipation of heavy demands for steam are for the purpose of avoiding unusual “peaks” in the demand made on the firebox and the uneconomical forcing of the fire. Very heavy firing is wasteful as compared with moderate rates of firing. Where demands upon the locomotive, such as may be caused by a heavy grade, can be anticipated a somewhat gradual building up of the fire will help to equalize the demands made upon the firebox. This practice will to a certain extent prevent high rates of combustion and so will be economical of fuel. The careful operation of the injectors before and during such “peaks” and the careful operation of the locomotive as a whole, together with the handling of the fire to the best advantage, will do much to prevent the necessity for very high rates of combustion and the loss of fuel which attends such periods of forced firing.

Still other precautions are for the purpose of eliminating or reducing coal losses which occur more or less independently of the efficiency of the combustion process. Coal when placed on tenders should be trimmed so that there shall be no loss through falling off on the road bed. Coal should not be allowed to fall or blow away from the engine deck. The sprinkler hose should be used enough to keep down dust and to prevent fine coal from blowing about.

Unnecessary stops for coal or water or other unnecessary stops which may be within the control of the engine crew should not be made. Each stop and start requires the burning of additional coal. Prevention of delays of this kind in so far as they may come within the control of enginemen will save coal.

The direct loss of coal or partially burned coal through the grates to the ashpan should, of course, be prevented in so far as possible. The careful handling of the grates and the exercise of care when starting, cleaning, or banking fires will save coal.

Locomotives should not be brought into terminals with a fire heavier than is necessary properly to handle the train and the locomotive. A large fire which must burn out or be dumped when the fire is cleaned means a direct waste of fuel.

Every pound of steam which can be saved in the operation of the air pumps or in the use of other steam using devices and every steam leak which can be prevented or stopped means a corresponding saving of fuel. In like manner the economical use of air means coal economy. Air leaks and wastes often mean much larger coal losses than is commonly realized.

It takes extra power to operate valves and other parts of the locomotive mechanism which are not properly lubricated and this waste of power means a waste of coal.

The economical use of steam, other than in the main cylinders, the economical use of air, the prevention of leaks whether of coal, water, steam, air, or heat, and proper lubrication all mean economy and coal saving.

The Significance of Smoke

The emission of visible smoke from the stack of a locomotive is evidence of the presence of unconsumed volatile matter and soot, or the heavy distillates of coal, and indicates that conditions in the firebox are not such as to promote fuel economy. The direct loss represented by the smoke itself is not serious, but the conditions of which smoke is an indication may often result in waste.

The prevention of smoke depends to a large extent upon an adequate air supply, its proper mixture with the combustible gases, and the maintenance in the combustion chamber or firebox of a temperature sufficiently high to insure the ignition and combustion of the distillates arising from the coal. These distillates must be heated quickly and kept at a high temperature until the process of combustion is completed. The brick arch is an aid in promoting better conditions in the firebox and consequently in reducing smoke, since it helps to mix the air and gases and to maintain a uniformly high firebox temperature. The careful use of steam jets is also an aid in reducing smoke.

In general, it should be recognized that the emission of smoke is an indication of unsatisfactory conditions in the firebox which should be corrected as promptly as possible.

The discharge from locomotive smoke stacks contains not only the unconsumed distillates of coal but an amount of cinders and unburned fuel particles which have a unit heating value equivalent to about three-fourths that of the original fuel. This discharge of cinders varies according to the rate of combustion from a fraction of one per cent to as much as twenty per cent of the coal fired. The amount discharged at high rates of combustion is proportionately much greater than at low rates. For this reason, as for others which are discussed elsewhere, firemen should endeavor to maintain as low and uniform a rate of combustion as will meet the demands made upon the locomotive.

V. COAL

14. *Kind of Fuel Used by Railroads.*—The fuel used by railroads is normally that which is nearest at hand, or that which is most easily and most cheaply obtainable. In the early days wood was extensively used in locomotives, but it has now practically disappeared as a fuel. In a few districts where oil is available it is used as locomotive fuel, but coal constitutes the fuel now almost universally used in locomotives.

The location of many railroads has been determined by the location of coal fields because, as noted elsewhere, not only do the railroads consume in their operation about 25 per cent of the coal output of the country, but about one-third of the freight hauled by railroads consists of coal. It is important, therefore, for railroads to have access whenever possible to coal fields, not only to insure their own supply of fuel, but also to insure a certain amount of freight traffic. Owing to these conditions practically every variety of coal available in the United States is used to a greater or less extent by the railroads.

15. *Classification of Coal.*—Some coals may be classified upon a strictly chemical basis, but in general it is necessary to consider both the chemical composition and the physical characteristics. The United States Geological Survey has proposed the term “rank” for the different kinds of coal as determined by the chemical and physical characteristics, but this term has not yet come into general use. Upon the basis of chemical and physical properties coals may be classified or ranked as *anthracite*, *semi-anthracite*, *semi-bituminous*, *bituminous*, *sub-bituminous*, and *lignite*.

All these coals are composed of the following materials in varying proportions:

Solid or fixed carbon which burns with a glow and with little or no flame.

Gases or volatile matter which escape from the coal when it is heated and which burn with a flame.

Gases or volatile matter and water which escape from the coal when it is heated and which do not burn.

Ash or mineral matter which will not burn and which remains as ashes after the carbon and gases are burned.

The relative proportions of the materials in different coals determine their value for particular purposes. Fuels having a large amount of fixed carbon and a relatively small amount of volatile matter burn with a short flame and the whole process of combustion takes place at or near the surface of the fuel bed. Such fuels can be burned without developing visible smoke. On the other hand, coals containing a relatively large amount of volatile matter and a lower amount of fixed carbon than the high carbon coals burn with a longer flame because the volume of combustible gases distilled from them is greater, and the combustion of these requires an appreciable period of time. Because of the difficulty of completely burning this greater amount of gas which escapes from the coal, the amount of visible smoke is usually greater, unless special devices are used for furnishing an adequate supply of air to burn this gas before it escapes.

The water and non-combustible gases which are present in all coals and which are detected only by chemical analysis escape up the stack unnoticed and without being of any benefit in the process of combustion. In fact, these constituents represent a definite loss because they do not furnish heat by combustion and because they absorb and carry off heat which would otherwise be available for useful work. The term *moisture* in coal does not refer to the water adhering to the surface of the lumps, but to that contained within the pores of the coal. Moisture in coal is not evident to the eye and a coal containing a high percentage of moisture by analysis may appear to be perfectly dry.

The ash content of different coals varies widely. It not only has no heating value, and, therefore, represents a portion of the coal for which no return is received, but it may hinder the free burning of the combustible components of the coal and, if it contains certain mineral substances, may by clinkering, greatly interfere with the process of combustion and with the cleaning of grates.

It should be clearly understood that ash will *not* burn and that no treatment with chemicals, secret processes, or other devices will cause it to burn. Ash is objectionable not only because it may interfere with the burning of the coal, but because it means an increased cost for handling.

The ash in coal may be classified under two divisions: (a) That which is a definite part of the coal itself and is invisible to the eye and which cannot, therefore, be separated by hand, and (b) That

which is due to rock, shale and slate, which becomes mixed with the coal in mining and which can be removed in great part either in the mine or in the tipple.

Anthracite

Anthracite, commonly known as "hard coal," contains a high percentage of fixed carbon, very little volatile, does not coke, and is smokeless. It was formerly extensively used for locomotive purposes by the so-called "anthracite" roads, or roads traversing the anthracite district of northeastern Pennsylvania. Owing, however, to the increasing value of and demand for anthracite for domestic purposes, it is now used on locomotives mainly for passenger service or where smokeless burning is required.

Semi-Anthracite

Semi-anthracite is a hard coal and has a high percentage of fixed carbon but has neither of these properties to so great an extent as has anthracite. It may be classed as an intermediate variety between true anthracite and true bituminous. The amount of semi-anthracite in the United States is small, and it is employed for railroad use only to a very limited extent.

Semi-Bituminous

The term "semi-bituminous" is unfortunate, since it implies a lower grade of coal than bituminous. Actually semi-bituminous coals are better than bituminous. Semi-bituminous coals have a relatively high percentage of fixed carbon which makes them nearly smokeless. Consequently most of these coals are known as "smokeless coals." Semi-bituminous coals, in general, have the highest heating value of any of the coals and are usually low in ash and moisture. They are also usually very friable, breaking easily into small pieces and dust. They are particularly adapted for purposes where smokeless combustion is essential, as with the navy. Their high value precludes their general use as locomotive fuel except upon the roads running through the districts in which the coal is mined.*

Semi-bituminous and bituminous coals may be either coking or non-coking. A true coking coal when fired swells, becomes pasty, and

*Semi-bituminous coals are mined in certain districts in West Virginia, Virginia, eastern Kentucky, western Maryland, and in some parts of Pennsylvania. Semi-bituminous coal is also mined in Arkansas and eastern Oklahoma and a small amount is found further west.

fuses into a mass of more or less porous coke. Such coke will burn without flame and will hold fire a considerable period. This fusing or coking takes place without respect to the size of the piece of coal. A non-coking coal does not swell and become pasty, but burns away gradually to ash, the pieces becoming smaller and smaller as combustion proceeds. There is a gradual gradation from true coking to true non-coking coals, and many coals cannot be distinctly placed in either class. Coal which will not coke on a furnace grate may, however, give good coke in by-product coke ovens, particularly when mixed with other more easily coking coals. This is the case with many Illinois coals.

Bituminous

The term "bituminous" coal as generally understood applies to a group of coals which have relatively high percentages of volatile matter. Generally the volatile matter and the fixed carbon are nearly equal, but this fact alone is not distinguishing, since the same statement may be made with regard to sub-bituminous coal and lignite. The principal characteristic which distinguishes bituminous coals from the lower ranks of coals, such as sub-bituminous and lignite, is its weathering property. Most of the bituminous coals can be exposed to the air for considerable periods, without material physical or chemical deterioration. Sub-bituminous and lignite coals, on the other hand, break up easily when exposed to the weather. Bituminous coals vary widely in their physical properties and in their heat producing qualities and many attempts have been made to subdivide them, but so far no scheme has met with general approval. The bituminous coals include some of the best coking coals, most of the gas coals, and the cannel coals. In general the bituminous coals decrease in value from the East toward the West, the highest rank of bituminous coal being found in the East and the lowest in the West. There are, however, some striking exceptions to this general rule.

The eastern bituminous coals contain from 5 to 10 per cent of ash, from 25 to 35 per cent of combustible gases, from 2 to 5 per cent of moisture and non-combustible gases, and from 55 to 65 per cent of fixed carbon. These coals are more generally of the coking variety than are the Middle West coals. In general, they are higher in heating value and lower in ash, but break up more easily and are not so well suited for transportation and for repeated handling as are many of the Middle West coals.



FIG. 13. DIAGRAM SHOWING THE CHEMICAL COMPOSITION AND HEAT VALUE OF THE SEVERAL RANKS OF COAL

The upper diagram shows the heat value of the samples of coal represented in the lower diagram, computed on the ash-free basis. The lower diagram shows the variations in the fixed carbon, the volatile matter, and the moisture of coals of different ranks, from lignite to anthracite, computed on samples as received, on the ash-free basis.

Bituminous coals are more extensively used in locomotives than other kinds. This fact is probably due to the wide geographical distribution of bituminous coal and to the many varieties which are available.

Fig. 13 shows graphically the proximate chemical composition of the various coals referred to and their heat producing values. The analyses have been recalculated to the "ash free" basis so as to make them strictly comparative.*

The lower diagram of Fig. 13 shows the following general differences between the different ranks of coal:

- (1) The proportion of fixed carbon increases quite regularly from lignite to anthracite.

- (2) The amount of moisture in the higher ranks of coals is small—it is about the same for semi-anthracite and high rank semi-bituminous—and increases rather rapidly for the lower ranks, lignite showing a very high percentage.

- (3) The greatest amount of volatile matter is found in the medium and low rank bituminous coals.

The upper diagram of Fig. 13 shows the heat values of the same coals on a similar "ash free" basis. It is sometimes wrongly inferred that the heat value of a coal depends upon its content of fixed carbon. This is not true, for the heat value of pure carbon is only 14,600 B. t. u., whereas coal No. 6 has a heat value of 15,480 B. t. u. The heat value of a coal depends largely upon the content of carbon and hydrogen. The carbon has a heat value of 14,600 B. t. u. and the hydrogen a value of 62,000 B. t. u. The greater heating value of coals containing less fixed carbon but more volatile matter than anthracite, for instance, is due to the fact that they contain hydrogen, which when burned produces greater heat than the same weight of carbon. Comprehensive tables of analyses of coal from all parts of the United States are contained in Bulletin 29 of the State Geological Survey, Urbana, Illinois, entitled "Purchase and Sale of Illinois Coal under Specifications," "by S. W. PARR, and in Bulletin 3 of the Illinois Coal Mining Investigations, Urbana, Ill., entitled "Chemical Study of Illinois Coal," by S. W. PARR and in the publications of the U. S. Bureau of Mines and U. S. Geological Survey, the latest of these being Professional Paper 100A previously mentioned.

*These values are given in U. S. Geological Survey Professional Paper 100A, "The Coal Fields of the United States," by M. R. Campbell.

16. *Preparation a Factor Affecting the Value of Coal.*—Coal occurs in the earth in beds or seams, and usually in a solid mass as a rock. In mining it is blasted with powder, shoveled into cars, and conveyed to the surface. In the process of mining and handling it becomes broken up into pieces of all sizes. It may have some rock or dirt from the floor and roof of the mine mixed with it or there may be bands of layers of shaly matter in the coal seam itself. Coal as it comes from the mine is, therefore, not usually in condition for direct delivery to the consumer, but should first be “prepared” in order to remove these impurities and to separate it into the proper sizes for various markets. The impurities are removed, in the large sizes of coal by picking them out by hand, and in the smaller sizes by treating the coal in cleaning machinery. Separation into different sizes is accomplished by sending the coal over screens having holes of the proper sizes.

As a general rule, railroads have used for locomotives run of mine coal or various sizes of lump and egg. Screenings have recently been used on stoker fired engines which are being employed more and more extensively.

17. *The Selection of Coal.*—The beginnings of fuel conservation may be made in the purchase of the coal. While the purchasing agent is frequently limited in his choice by the presence of mines on the railway line, by the necessity of taking sizes of coal for which there is little other market, and by the fact that not all sizes are available in sufficient quantities for railway use, there are frequently occasions when these limitations are largely removed. Under these circumstances the size of coal should be chosen not only with respect to its price but with respect to its steam producing capacity.

There is considerable difference between the steam producing capacity in locomotives of various sizes of coal. No one expects, for example, to get as much steam from a ton of screenings burned in a locomotive as from a ton of mine run coal. Tests* recently made on a Mikado locomotive in the locomotive laboratory of the University of Illinois show the relative value in locomotive service of six different sizes of coal. All six sizes were from the same mine in Franklin County, Illinois, and while the results of the tests are strictly appli-

*“Comparative Tests of Six Sizes of Illinois Coal on a Mikado Locomotive,” Univ. of Ill. Eng. Exp. Sta., Bul. 101, 1917.

cable only to this coal, they probably apply in some measure to the great bulk of soft coal used on locomotives.

The tests were run at two rates of combustion; a medium rate at which about 4,000 pounds of coal were burned per hour, and a high rate at which about 7,500 pounds were burned per hour. Comparisons between the sizes were made upon the basis of their steam producing ability, that is, upon the basis of the evaporation per pound of coal which took place with each size.

At the medium rate the coals stand in the following order: 3-inch by 6-inch egg, mine run, 2-inch lump, 2-inch by 3-inch nut, 2-inch screenings, and $1\frac{1}{4}$ -inch screenings. Assuming mine run coal to produce 100 per cent of steam, the egg coal produced 2 per cent more and the lump and nut coals respectively 1 per cent and 2 per cent less. The 2-inch screenings produced 7 per cent less steam, and the $1\frac{1}{4}$ -inch screenings 15 per cent less.

The relation is somewhat different for the higher rate of combustion. Again assuming the mine run in the high rate test to produce 100 per cent of steam, the nut coal produced 6 per cent more, the egg 5 per cent more and the lump 3 per cent less. The 2-inch and $1\frac{1}{4}$ -inch screenings produced respectively 13 per cent and 18 per cent less.

These facts should enable the railway purchasing agent to form some idea of the sizes of coal with the greatest steam producing capacity although the fact that the coal used in these tests came from a single mine should not be overlooked. Obviously the choice of coal can seldom be made solely on the basis of the steam producing qualities of the fuel, since the market price must also be taken into consideration. While no general statement can be made regarding the relative prices warranted for the different sizes of fuel, the question is somewhat more fully discussed in the bulletin mentioned.

In the present emergency all purchasers of fuel are glad to get coal of any kind and they are allowed little opportunity to choose. The problem is to get coal enough of any sort for the purposes in hand, but these temporary conditions ought not to prevent the recognition of the fact that a considerable saving in coal and money may be effected by a proper choice of fuel.

18. *Purchase of Coal.*—The custom of purchasing coal on the B. t. u. basis is increasing and if the specifications for such purchase are properly drawn and understood it is the logical way to buy coal.

It is equivalent to buying so many heat units instead of so many tons of coal and is an effort to get the greatest amount of heat for a dollar. Upon this basis a purchaser should be able to determine whether a low priced coal which gives less efficient boiler service and requires more labor and expense in handling ashes is really cheaper than a higher priced coal.

With reference to the selection of most locomotive coals, the B. t. u. value and the percentage of ash furnish a general guide to their relative merits. The ash content and character directly affect the B. t. u. value, so that the relative value may be expressed with fair accuracy by the B. t. u. value alone, although the value of any coal drops off more rapidly than its B. t. u. value when the ash content exceeds 10 or 15 per cent.

It should be understood that the purchase of coal on the B. t. u. basis does not insure maximum efficiency from the fuel, because a high grade coal carelessly fired or having a bad clinkering ash may give poorer results than a low grade coal carefully fired. In other words, the high B. t. u. value of a coal establishes a presumption in favor of that coal which must be tested by actual trial under good operating conditions. The person who furnishes coal of a high B. t. u. value cannot be held responsible for poor results obtained through improper use. The great disadvantage with regard to the purchase of coal on the B. t. u. basis lies in the difficulty of obtaining samples for analysis which are truly representative of the coal received by the consumer. Too much emphasis can hardly be placed upon the necessity for exercising great care in the taking of samples in order that they may truly represent the coal for which they stand.

19. *Storage of Coal.*—Coal is stored by railroads to guard against a shortage which may result from failure to receive coal from the mines on account of strikes, explosions, interruptions in traffic, or other causes, and to use coal loading equipment in company service when it is not in demand for commercial service. There is an advantage also in hauling large quantities of coal in the summer months when the cost of haulage is lower than at any other season.

Railroad storage has been very fully discussed in the Proceedings of the International Railway Fuel Association and very full details will be found in Circular 6 of the Engineering Experiment Station of the University of Illinois. The Fuel Station Committee of the Inter-

national Railway Fuel Association suggests that all new mechanical coaling plants be so designed as to provide a storage adjunct, so that coal may be unloaded into a receiving hopper from which it may be distributed either to the coaling station direct or to a storage pile. The plant should be designed so as to permit the recovery of the coal from the storage pile without the use of railroad cars.

The usual method of storing railroad coal, as illustrated in Fig. 14, is to start a pile on the ground and gradually to raise the track on top of the coal pile until a height of 10 to 20 feet is reached, the end of the track being supported on a crib as shown in Fig. 15. The coal is then reclaimed with a locomotive crane or steam shovel, or by hand shoveling into cars.

Although this is a simple and cheap way to store coal, the conditions of storage are favorable to spontaneous combustion. Especially is this true since run of mine coal is generally stored and the weight of the locomotive and loaded cars on top of the coal break it up and produce fine material in the center of the pile while the lumps roll to the bottom of the outside slope and afford passages through which the air may reach the fine material. If stored in piles as shown in Fig. 14 the pile should not be continuous, but passageways should be left through the pile at regular intervals in order to facilitate the removal of the coal in the case of heating.

Fig. 16 shows a circular storage pile used in connection with a coaling station, and Fig. 17 a large coaling station. Many of the railroads issue instructions with regard to the method of storing coal, but these instructions are too frequently not carried out.

The following general conclusions regarding storage are based upon answers to a questionnaire sent to several hundred firms and individuals storing coal under different conditions. It is believed that the statements made represent very closely the present consensus of opinion on the subject.

Kinds and Sizes of Coal which may be Safely Stored

Although it is undoubtedly true that some coals may be stored with greater safety than others, the danger from spontaneous combustion is due more to improper preparation and piling of coal than to the kind of coal stored.

Most varieties of bituminous coal may be safely stored if of proper size and if free from fine coal and dust. The coal must be handled in



FIG. 14. A LONG PILE OF STORED COAL



FIG. 15. STORAGE COAL WITH UNLOADING TRACK AND CRIB

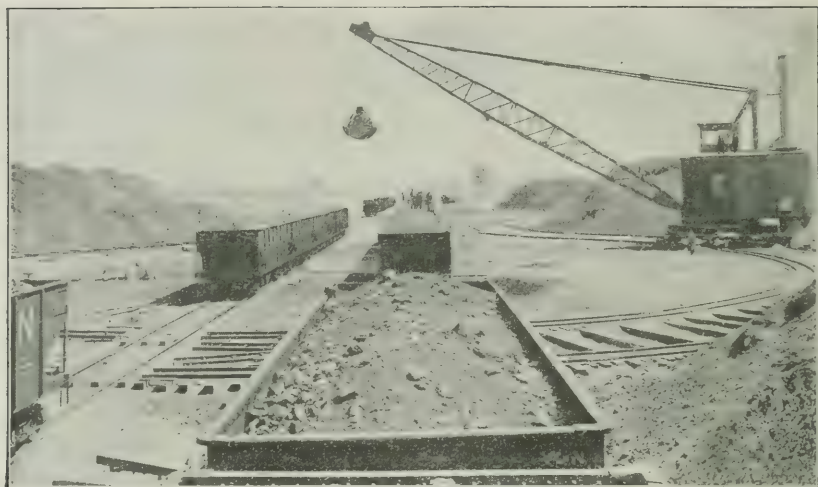


FIG. 16. A CIRCULAR PILE OF STORED COAL

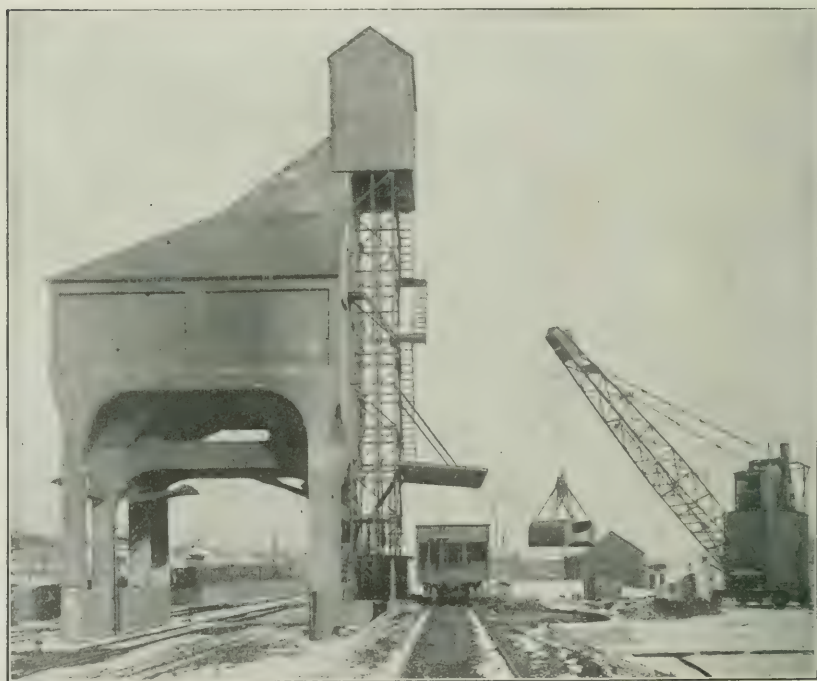


FIG. 17. A COAL STORAGE STATION AND CHUTE

such manner as to prevent excessive breakage and the consequent production of much fine coal and dust when being placed in storage, because spontaneous combustion is due mainly to the oxidation of the coal surface. The danger of spontaneous combustion in storing coal is very greatly reduced, if not entirely eliminated, by storing only lump coal from which the dust and fine coal have been removed. Of two coals, the one which is less friable should be chosen for storage purposes because less dust and fine coal will be produced in its handling. All varieties of bituminous coal can be stored under water, since water excludes the air and prevents spontaneous combustion.

Fine coal or slack has sometimes been safely stored in cases in which air has been excluded from the interior of the pile. Exclusion of air from the interior may be accomplished (1) by a closely sealed wall built around the pile or (2) by close packing of the fine coal. Any pile of slack requires careful watching to detect evidences of heating and means should be provided for moving the coal promptly if heat develops. The only absolutely safe way to store slack or fine coal is under water.

Many varieties of mine run coal cannot be stored safely because of the presence of fine coal and dust mixed with the lumps.

Coal exposed to the air for some time may become "seasoned" and thus may be less liable to spontaneous combustion because of the oxidation of the surfaces of the lumps of coal, but opinions are by no means unanimous on this point.

It is believed by many that damp coal or coal stored on a damp base is peculiarly liable to spontaneous combustion, but the evidence on this point is by no means conclusive. It is safer not to dampen the coal when or after it is placed in storage.

The Effect of Sulphur on Spontaneous Combustion

It has been shown by experimentation that the sulphur contained in coal in the form of pyrites is not the chief source of spontaneous combustion, as was formerly supposed, but the oxidation of the sulphur in the coal may assist in breaking up the lumps of coal and thus may increase the amount of fine coal which is particularly liable to rapid oxidation. Even this opinion is not unanimously endorsed. In spite of experimental data showing that sulphur is not the determining element in spontaneous combustion, the opinion is wide-spread that,

if possible, it is well for storage purposes to choose a coal with a low sulphur content.

Method of Piling Coal

To prevent spontaneous combustion, coal should be so piled that air may circulate freely through it and thus may carry off the heat due to oxidation of the carbon, or it should be so closely packed that air cannot enter the pile and oxidize the fine coal.

Stratification or segregation of fine and lump coal should be avoided, since an open stratum of coarse lumps of coal provides a passage through which air may enter and come in contact with the fine coal, thus oxidizing it and starting combustion.

If space permits, low piles are preferable since in low piles the coal is more fully exposed to the air and is better cooled than in high piles and in case of heating it can be more readily and quickly moved. A disadvantage of high piles lies in the greater difficulty of moving the coal quickly, if necessary. The idea that a high pile causes heating at the bottom is erroneous, since as many fires take place near the top as near the bottom, and as many near the outside as near the interior of the pile. If possible, the coal should be divided by alleyways so as to facilitate rapid loading out the coal in case of necessity, and so that an entire coal pile may not be endangered by a local fire.

Much of the attempted ventilation of coal piles has been inadequately done through the use of only an occasional ventilation pipe, which has been not much more than a place in which to insert a thermometer. The practice of placing ventilating pipes closely together has been used in Canada and is reported to be effective.

Water is an effective agent in quenching fire in a coal pile only if it can be applied in sufficient quantities to extinguish the fire and to cool the mass. A small quantity of water is not effective. Unless there is an ample supply of water thoroughly to quench the fire and to cool the pile, it is very dangerous to add any water to a coal pile.

Coals of different varieties should if possible not be mixed in storage, for the coal possessing the greatest tendency toward spontaneous combustion may jeopardize the safety of other varieties not so liable to spontaneous combustion.

The Effects of Storage upon the Properties of Coal

The heating value of coal as expressed in B. t. u. is decreased very little by storage, but the opinion is wide-spread that storage coal burns

less freely than fresh coal. Storage does, however, have the physical effect of producing an amount of fine coal and dust which, when fired in locomotives, tends to increase the percentage of unburned coal and cinders discharged through the stack. Dirt, cinders or other foreign matter are sometimes picked up when stored coal is reclaimed and the burning qualities of the fuel thereby seriously impaired.

The coking properties of most coals seem to decrease as a result of storage, but coals vary greatly in this respect.

The deterioration of coal stored under water is negligible, and such coal absorbs very little extra moisture. If only part of a coal pile is submerged, the part exposed to the air is still liable to spontaneous combustion.

Additional Precautions

The best preventive of loss in coal storage is regularly to inspect the pile. If the temperature reaches 150 degrees F., the pile should be carefully watched and if the temperature rises to 175 or 180 degrees F. the coal should be removed as promptly as possible. The coal should be thoroughly cooled before being replaced in storage.

Storage appliances and arrangements should be so designed as to make it possible to remove the coal quickly if necessary, and coal should not be stored in large piles unless provision is made for loading it out quickly.

Pieces of wood, greasy waste, or other easily combustible material mixed in a coal pile may form a starting point for a fire, and every effort should be made to keep such material from the coal as it is being placed in storage.

It is important that coal in storage should not be subjected to such external sources of heat as steam pipes, because the susceptibility of coal to spontaneous combustion increases rapidly as the temperature rises.

Expense of Storing Coal

The following statements or estimates of the expense of storing coal are given by the railroads noted:

TABLE 3 *
EXPENSE OF STORING COAL

Source of Information	Cost in Dollars per Ton		
	Storing	Reclaiming	Total [*]
Clinchfield Fuel Co., Dante, Va., Crane & Trestle.....	.0671	.0655	.1326
Estimate of C. G. Hall, former Secretary Int. Ry. Fuel Association.....			.2628
Missouri, Kansas & Texas Railroad, including cost of track	.035	.035	.07
Chicago, Lake Shore & South Bend Railroad.....			.12
Grand Trunk Pacific Ry.....	.08	.062	.142
Atlantic Coast Line.....			.04-.05
Central of Georgia Railroad.....	.0258	.0209	.0467

* These estimates vary widely according to the conditions under which the storing was done and for this reason are not directly comparable. The conditions of storage in each of the cases covered in this table are set forth in detail in Circular 6, entitled "The Storage of Bituminous Coal," by H. H. Stock, Univ. of Ill. Eng. Exp. Sta., March, 1918.

VI. SUMMARY

20. *Ways in which Locomotive Coal may be Saved.*—Large coal savings may be made by slightly modifying the methods of handling transportation, by the use of carefully designed equipment and auxiliary apparatus, by better maintenance of equipment, by better handling of locomotives when not hauling trains, and by more careful attention to the firing and operation of the locomotive when hauling trains. The importance of coöperation in the matter of fuel economy should not be overlooked.

In Handling Transportation

Transportation should be so handled, train schedules should be so arranged, and the calling of locomotives should be so carefully watched that waste of coal through unnecessary terminal delays and delays on sidings may be eliminated. Thirty million tons of coal per year are burned on locomotives when they are not hauling trains. Transportation officials have an opportunity to save some of this coal.

In Locomotive Design

The responsibility for installing equipment of the best design and for the use of at least some of the most approved fuel saving devices, such as the superheater and brick arch, rests upon railway executive officials. The fact that changes along such lines take time and require capital expenditure may possibly remove them from the class of emergency measures, but this fact does not lessen the possibility of effecting large coal savings through these means. A more extended use of fuel saving devices of proved merit should be made.

In Maintenance

Proper maintenance of equipment, particularly of locomotives, is one of the principal means through which large fuel savings may be made. The importance of this matter is often overlooked or is not fully appreciated. While a large number of persons is concerned with maintenance matters, the responsibility rests principally upon officials of the mechanical department and upon the shop and round-house forces.

In Handling and Care of Locomotives

In addition to matters of maintenance, roundhouse men are in position to effect substantial savings in the direct use of coal when cleaning, building, and maintaining locomotive fires, and they can effect savings of still greater importance through proper boiler washing and cleaning of flues. The care which a locomotive receives and the work which is done upon it between trips is of the greatest importance in relation to fuel economy. Adequate roundhouse and other terminal facilities should be provided as rapidly as possible.

In Locomotive Operation

Engine crews are in direct charge, hauling trains, while 80 per cent of the locomotive fuel is being burned. While the extent of the saving to be effected in the burning of this fuel often depends in part upon the design, upon the maintenance and care of the equipment, and upon activities of transportation officials, there still remain with the engineers and firemen opportunities for fuel saving of the greatest importance.

Coöperation

The highest degree of economy in the use of locomotive fuel cannot be attained without coöperation. Executive officials must furnish funds for the equipment and labor necessary to promote fuel saving work. There must be close coöperation between the transportation and mechanical departments in order that terminal and other delays may be reduced and that power and fuel may be handled and used to the best advantage. Shop men and officials must appreciate the importance of proper maintenance of locomotives, cars, and auxiliary equipment. Roundhouse forces and engine crews must work together if locomotives are to be economical in the use of coal both while on the road and while being cared for between trips. Engineers must render carefully prepared and specific work reports, and the roundhouse forces must act in a thorough going way upon the matters reported and return locomotives to the roadmen in the best possible condition.

21. *Estimated Possible Saving to be Effected in the Use of Locomotive Coal.*—The railways used in locomotives during the year 1917 about 140,000,000 tons of coal. The corresponding amount for 1918

will be about 150,000,000 tons. A saving of six per cent of this fuel is readily possible through the coöperative action of railroad officials and employes. Such a saving would amount to 9,000,000 tons. A much larger saving is ultimately possible through a general improvement in equipment and the adoption of approved fuel saving devices.

Six per cent of the locomotive coal is sufficient to operate 2500 additional modern locomotives; it is equivalent to the fuel supply of some of our largest railway systems; it would coal sufficient transports to take an army of many millions of men to France.

Every person connected with the railroad service should ask himself:

- (1) How much coal can be saved by the group of which I am a part?
- (2) What are the ways in which I can assist in saving coal?
- (3) Am I doing my part as an individual to save coal?
- (4) Am I coöperating with others so as to assist in securing the greatest combined saving?

Executive Officials and Transportation Forces

Executive officials, transportation officials and employes, particularly superintendents, train masters, dispatchers, fuel agents, and inspectors can effect coal savings in many ways. They should be able materially to reduce stand-by losses and to effect economies in connection with the loading of locomotives and in the selection, distribution, and handling of locomotive coal.

Operating officials should thoroughly acquaint themselves with the fuel problem and should take such action as will impress all officials and employes under them with the importance and possibilities of fuel savings. Too much emphasis can hardly be placed upon the necessity of operating officials taking an active interest in the matter of fuel economy and upon their giving personal and financial support to fuel saving measures.

Engines should, for fuel economy, neither be operated with very light loads nor with loads so heavy that they cause poor combustion conditions, or occasion undue delays through stalling or other accidents.

If possible reduce speed in passenger work or eliminate some passenger runs. Coal savings can be made in this way.

Arrange freight train schedules and the methods of calling engines so as to prevent locomotives standing and wasting coal through delays at terminals, on sidings, at meeting points, and at ashpits.

Assist in furnishing the most suitable kind of coal for the various types of locomotives or classes of service.

Prevent loss of coal in transit, at coal chutes, and at storage piles.

See that coal is so handled that it is not unnecessarily broken up, thereby impairing its value as fuel.

Executive and Motive Power Officials

Executives including motive power officials can effect important fuel savings through matters of design, improved equipment, and better shop and roundhouse facilities. They should consider the purchase of and should apply, so far as may be possible, improved motive power and equipment. They should install as rapidly as possible such fuel saving devices as the superheater and the brick arch; and they should improve locomotive terminal facilities and improve or extend existing shop and roundhouse equipment to the extent necessary to promote better maintenance and care of locomotives.

Motive Power Officials and Shop and Roundhouse Forces

Mechanical department employes and officials concerned with the maintenance of equipment have opportunity to stop some of the largest coal losses which take place in locomotive operation. Every feature of shop and roundhouse management, equipment, or operation which will make it possible to maintain locomotives in the best possible condition means a saving of fuel. A locomotive in very poor condition may use from 20 to 40 per cent more fuel than when in thoroughly good condition. Those responsible for the proper maintenance of locomotives are responsible for a large part of the coal saving that it is possible to make at the present time. Engineers and firemen, no matter how skilful or careful, cannot use coal economically on poorly maintained equipment. It is also more difficult for engineers and firemen to know whether or not they are handling their locomotive to the best advantage when it is not in proper condition, and the incentive to meet all the requirements of economical operation is lacking when poorly maintained equipment is being handled.

Locomotives should be maintained to prevent serious steam, air and water leaks.

Steam pipes and superheaters should be tested and kept free from leaks.

Leaks past the cylinder and valve packing and past rod packings should be prevented.

Leaks from the boiler through leaky mudring, flues, or at other points should be prevented.

Air leaks to the front end should be stopped.

Air pumps and all auxiliary steam using apparatus should be kept in the best possible condition. Locomotive friction should be kept as low as possible by having the mechanism well maintained.

Radiation losses should be kept as low as possible through properly maintained lagging.

Exhaust nozzle opening should be as large as is consistent with the proper steaming of the locomotive.

The locomotive should be equipped with injectors of the proper size.

All auxiliary apparatus such as power reverse mechanism and automatic firedoors should be in condition to be used to the best advantage.

Firemen cannot meet the requirements for maintaining proper firebox conditions unless firedoors, arches, grates, ashpans, and dampers are in good condition, and unless the flues are kept clean. Shop and roundhouse men must meet the requirements of proper maintenance.

Roundhouse Forces and Hostlers

Roundhouse men and officers concerned with the handling and care of the locomotive between trips are immediately concerned with keeping the locomotive in the best possible condition. It has already been pointed out that one of the best means of effecting a saving of coal is by keeping locomotives in somewhat better general condition. This is to be done largely through proper cleaning of flues, washing of boilers, and attention to light repairs. Savings are to be made in connection with the coal which is used on the locomotive while it is being turned, particularly in connection with coal or live fire lost at the ashpit.

Flues should be cleaned after every trip, and special attention should be given to superheater flues. Boilers should be washed frequently.

When locomotives are cleaned the firebox should be thoroughly inspected in order that all necessary cleaning and repairs relating to grates, arches, and flues may be attended to.

In cleaning, building, banking and keeping up fires, every effort should be made to save fuel.

Engineers and Firemen

Engineers and firemen who are in charge while the greater part of the coal is used must accept a considerable part of the responsibility for effecting savings. Engineers through their methods of handling the locomotive can increase or decrease the amount of coal burned to a very marked degree. Firemen by maintaining the best possible combustion conditions can reduce some of the most important losses which occur, such as those to the ashpit and to the stack.

Firemen should keep constantly in mind the three conditions which are necessary for complete combustion; first, that enough and not too much air be admitted to the firebox; secondly, that the air be thoroughly mixed with the coal burning on the grate and with the combustible gases arising from the fuel bed; thirdly, that a sufficiently high and uniform firebox temperature be maintained.

Determine how these conditions can be produced and endeavor to obtain them. Maintain a level, bright fire.

All lumps of coal should be broken into pieces not larger than three or four inches in diameter. Ordinarily, coal should be broken to the proper size before being placed on the tender. In so far as is possible, the fireman should do his part to avoid losses which are caused by firing large lumps of coal.

Do not let banks or holes form in the fire.

Prevent clinker formation so far as possible.

Fire the coal in small amounts; from one to four shovelsful at a time.

Spread the coal over the brightest and thinnest parts of the fire.

Close the door after each shovelful of coal is fired.

Shake the grates only when necessary, and then only lightly. Avoid disturbing the fuel bed to such an extent that holes and additional clinker form and that live fuel is lost to the ashpan. Preferably, the grates should not be shaken when running, particularly when the locomotive is working very hard. Air for combustion comes through the grates and firebed. When coming into the firebox in this way it

is more nearly uniformly distributed than if it comes through the door and so will be better mixed with the burning fuel and gases.

Do not rake the fire unless it seems absolutely necessary in order to fill a hole or break up a bank.

Anticipate heavy demands which may be made upon the locomotive and have the fire built up as much as may be possible to meet them.

Anticipate periods when very light demands may be made upon the locomotive and avoid "popping off" or opening the firedoor.

Do not have more fire than is necessary when the terminal is reached.

Do not let coal fall or blow away from the engine deck. Keep the engine deck clean. Use the sprinkler hose enough to keep down dust and prevent fine coal from blowing away.

Locomotive engineers should handle the throttle and the reverse lever so as to be economical of steam and should assist the fireman by using as little steam as possible and by operating the locomotive in such manner as to disturb as little as possible uniform conditions in the firebox.

In general a full throttle opening should be used, exceptions being when starting or drifting, or when working with short cut-off.

Injectors should feed the boiler at a fairly uniform rate, and should be so handled as to assist the fireman in maintaining uniform and satisfactory firebox conditions. The boiler should not be filled to a point likely to cause priming.

Waste of steam through safety valves should be avoided. All auxiliary apparatus should be handled so as to be as economical of steam and air as is possible.

Unnecessary stops and delays should be avoided so far as possible.

LIST OF PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

- Bulletin No. 1.* Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*
- Circular No. 1.* High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*
- Bulletin No. 2.* Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*
- Circular No. 2.* Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*
- Circular No. 3.* Fuel Tests with Illinois Coal (Compiled from tests made by the Technological Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907), by L. P. Breckenridge and Paul Diserens. 1908. *Thirty cents.*
- Bulletin No. 3.* The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*
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